INVISIBLE INFLUENCE: THE ROLE OF HUMAN SOCIAL OLFACTORY CUES IN ECOLOGICALLY RELEVANT INTERACTIONS

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INVISIBLE INFLUENCE: THE ROLE OF HUMAN SOCIAL OLFACTORY CUES IN ECOLOGICALLY RELEVANT INTERACTIONS

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Abstract

A growing body of research indicates that body odor is important in human social communication, signaling information as varied as mate fitness, emotional state, and health status. Though research shows that body odor production is not limited to the axilla (armpits), most studies employ axillary sweat collected on t-shirts or pads, removing these samples from the olfactory context of whole body odor, as well as eschewing the evaluation of these odors from a realistic social distance. Current research employs odor samples donated by participants asked to avoid perfumes and deodorants, change their diets, and avoid such daily habits as drinking alcohol and sleeping with partners. In day-to-day life, however, people do engage in these activities. I label body odor that includes these daily modifications *diplomatic odor*, whereas I refer to body odor devoid of all exogenous odor influences as *natural odor*. Finally, while there has been great interest in the use of olfactory information for mate selection, there has been little investigation into its potential uses in first impressions and platonic friendship, and for this reason I focus solely on intrasexual female interactions. In this dissertation, I demonstrate that 1) people perceive consistent olfactory signals at social distances in realistic interactions, and that these signals

convey different information depending on whether the donors present their diplomatic or natural body odor; 2) that body odors collected on t-shirts convey some - but not all - of the same information gleaned in an interaction with a live odor donor; 3) that perfume does not affect discrimination between individual body odors, 4) that learned responses to body odors can affect visual perception of social signals, and 5) that, although participants display social preferences based on olfactory information collected on t-shirts, they do not rely on these cues for informing first impressions in brief, multimodal encounters. As a whole, this dissertation demonstrates the social relevance of diplomatic olfactory cues in naturalistic interactions, and suggests that future work consider both natural and diplomatic odor influences, presented in realistic social contexts, in order to gain insight into the functional role of body odor in real life.

BIOGRAPHICAL SKETCH

Jessica Gaby received her undergraduate degree from the University of Miami in 2005. A B.A. in Psychology, she minored in Biology and Studio Art, graduating magna cum laude with honors in her major. She spent the next six years working as a barista, dancing in a company in Austin, TX, and teaching preschool before the siren song of academia lured her to apply for graduate programs. She entered Cornell University as a Ph.D. student in Psychology in the fall of 2011. Choosing Cornell is one of the best decisions she has ever made.

This dissertation is dedicated to my parents. Without your love and support, I would be nothing. Without you, I would not be.

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CHAPTER 1

INTRODUCTION

In the literature on human olfaction, it is difficult to ignore how often authors mention that the human sense of smell is generally regarded as weak; overlooked for the flashier and more oft-studied sensory modalities of sight and sound; excluded from the vernacular of sensory science to such an extent that describing odors in the English language frequently requires descriptors originally used for other senses, such as *sweet, sharp*, or *bright*. And yet, despite the frequency with which olfaction seems to be neglected, the sense of smell is deeply and functionally intertwined in our daily activities, our emotional states, and our social interactions. As most anosmics will tell you, a world without smell is lonelier, more dangerous, flavorless.

So how, exactly, does olfaction play into our daily lives? In addition to its tight link with food choice and flavor, the sense of smell alerts us to environmental factors undetectable to the other sensory modalities. Smell is the first warning sign of fire. It announces to us that rain will soon fall. Smell tells us that we ought to check on our cookies in the oven, that our babies need a diaper change, that the milk in the fridge has gone sour. Smell helps us bond with our lovers and children. Without the sense of smell, the small but important trappings of everyday life are amiss, and it is often only with the loss of olfactory function that we notice the myriad ways in which our life without it is poorer.

This is no mistake. The sense of smell is wired in such a way that a large portion of olfactory processing is conducted outside of conscious awareness. We can observe this phenomenon in action by examining the behavioral effects of subthreshold odors. Odors below the level of conscious awareness can modify neural processing (Lundström, Boyle, Zatorre, & Jones-Gotman, 2008), increase the startle response (Prehn, Ohrt, Sojka, Ferstl, & Pause, 2006), shift social preferences for faces (Li, Moallem, Paller, & Gottfried, 2007), modify food choices (Gaillet-Torrent, Sulmont-Rossé, Issanchou, Chabanet, & Chambaron, 2014) and induce physiological reactions (de Groot, Smeets, Kaldewaij, Duijndam, & Semin, 2012). Olfactory stimuli have the power to evoke deeply emotional memories (Willander & Larsson, 2007), thanks to the direct link between olfactory processing areas and the amygdala-hippocampal complex (Herz, Eliassen, Beland, & Souza, 2004), ensuring that, in spite of its neglected status among the senses, olfaction plays a vital role in our emotional lives.

Ontologically, olfaction is one of the earliest senses to develop. Infants' ability to recognize their own amniotic fluid shortly after birth (Schaal, Marlier, & Soussignan, 1998), combined with their preference for the odors of foods consumed by their mothers while in utero (Schaal, Marlier, & Soussignan, 2000), implies that olfactory processing is functional long before birth. Once infants have exited the womb, olfaction plays an important role in nursing behavior and mother-infant bonding (Porter, Makin, Davis, & Christensen, 1992; Porter & Winberg, 1999). Olfaction helps to dictate early food preferences (Beauchamp & Mennella, 2009; Mennella, Jagnow, & Beauchamp, 2001) and allows both children and adults to discriminate kin from non-kin (for an excellent review, see Lenochová & Havlicek, 2008), important in both initiating and maintaining family bonds, as well as avoiding inbreeding. As we move forward developmentally, olfaction is involved in feeding behavior (Ventura & Worobey, 2013), consumer choices (Dixit, 2001; Doucé, Poels, Janssens, & De Backer, 2013), friendship maintenance (Mallet & Schaal, 1998; Olsson, Barnard, & Turri, 2006), and mate choice (for review, see Lübke & Pause, 2015), and is important in initiating and maintaining romantic relationships (Croy, Bojanowski, & Hummel, 2013).

One particular class of odorants seems to have a privileged role in human social interactions. Though the terminology is hotly debated (Doty, 2010), humans do seem to emit chemical signals with social value, or chemosignals. These signals are important in individual recognition (Porter, Cernoch, & Balogh, 1985; Roberts et al., 2005), as well as communication of sexual signals (Gildersleeve, Haselton, Larson, & Pillsworth, 2012; Kuukasjarvi et al., 2004), emotion (Zhou & Chen, 2011), and personal information such as health (Olsson et al., 2014) and sexual orientation (Lübke, Hoenen, & Pause, 2012; Martins et al., 2005).

The particular chemical composition of olfactory social signals conveying emotional information produced by the body is, as yet, unknown (de Groot, Smeets, & Semin, 2015). However, sweat collected from individuals in highly emotional states has been shown to affect both behavior and neural activity. Sweat from first-time skydivers, for example, activated areas of the brain associated with vigilance and emotional processing (Mujica-Parodi et al., 2009), while sweat collected from individuals completing a high ropes course triggered increased risk-taking during a gambling task (Haegler et al., 2010). Additionally, individuals are able to distinguish between sweat collected from those experiencing fearful stimuli and those experiencing positive or neutral stimuli (Cantafio, 2003; Chen & Haviland-Jones, 2000), though it appears that there are individual differences in the ability to accurately identify the valence of these odors (Haviland-Jones, McGuire, & Wilson, 2016). Fearful, disgusted, and happy sweat have also been shown to activate emotional mimicry in perceivers (de Groot et al., 2015; de Groot et al., 2015; de Groot et al., 2012), and sweat collected from anxious and aggressive individuals has been shown to sharpen the discrimination of emotionally ambiguous faces (Mutic, Parma, Brünner, & Freiherr, 2015; Wudarczyk et al., 2016).

Though we do not know the specific molecules involves in these emotional signals, it is clear that each individual has an "odor print," akin to the human fingerprint in individuality, and reliably distinguishable via gas chromatography (Penn et al., 2007; Prokop-Prigge, Greene, Varallo, Wysocki, & Preti, 2016). The smells we recognize as body odor are composed mostly of volatile organic compounds (VOCs) produced by the interactions of odorless sweat and sebum excreted by the apocrine, eccrine, and sebaceous glands of the skin with cutaneous microflora, specifically *Corenybacterium* and *Staphylococcus* (Troccaz et al., 2015) that metabolize these secretions (for a brief review, see Kippenberger et al., 2012). Apocrine glands, concentrated in the axilla, groin, and areolas, are thought to be the most prominent contributors to socially communicative body odor (Prokop-Prigge et al., 2016); the sweat excreted from these glands contains 16-androstene steroids (Havlicek, Murray, Saxton, & Roberts, 2010), specifically the putative human pheromones androstenone and androstedianone (Lübke & Pause, 2014; Lundström, Gonçalves, Esteves, & Olsson, 2003). Sebaceous glands, found all over the body but in high concentrations on the forehead, upper chest, upper back and scalp, excrete waxy substances responsible for keeping the skin moisturized, but have also been shown to contribute to body odor (Gallagher et al., 2008). Eccrine glands, distributed all over the skin, are involved in temperature control for the body, and mainly produce sweat for cooling. However, the bacterial breakdown of this sweat also contributes to body odor (Draelos, 2001).

Individual odor prints appear to be strongly influenced by a highly polymorphic component of the immune system, the human leukocyte antigen (HLA). HLA genotype determines the natural pathogenic immunities of an organism, and can therefore be conceptualized as the "immunological identity" of an individual (Aksenov et al., 2012). HLA contributes to the production of VOCs on a cellular level (Aksenov et al., 2012), and both rodents (Schellinck, Slotnick, & Brown, 1997) and humans (Jacob, McClintock, Zelano, & Ober, 2002) can distinguish single allele differences in HLA based on body odor. In other mammals, the HLA is termed the major histocompatibility complex (MHC), and many species use olfactory cues related to MHC both for kin identification and in mate choice (Penn & Potts, 1998; Schellinck, Slotnick, & Brown, 1997), as well as individual recognition (Johnston & Bullock, 2001). In particular, HLA/MHC class I proteins are expressed in almost all somatic cells of the body, and it is the odors associated with these particular genes that appear to be responsible for mate satisfaction in humans (Kromer et al., 2016). HLA-related odors are traditionally thought to be concentrated in the axilla, but one recent study calls this notion into question, as axillary odors appear not to vary according to HLA type (Natsch 2010). Natsch suggests that other areas of the body may be a richer source of HLA-associated body odor, highlighting the potential role of sebaceous and eccrine glands in the production of individual odors.

In addition to HLA's effect on individual body odor, HLA allelotype is also associated with personal fragrance choices. Milinski and Wedekind's (2001) seminal study revealed that those with specific allelotypes were more likely to choose particular fragrances as potential perfumes for themselves, but not for others. This work is supported by more recent findings (Hämmerli, Schweisgut, & Kaegi, 2012; Milinski, Croy, Hummel, & Boehm, 2013). Other factors also influence fragrance choice: cultural background contributes to feelings and beliefs about body odor (Ferdenzi et al., 2013; see Havlíček & Roberts, 2013 for an excellent review), as well as determining available and acceptable fragrance ingredients (Ayabe-Kanamura et al., 1998; Lindqvist, 2012).

In daily life, it is rare to encounter an individual who has made no modifications to their natural body odor. Because the use of deodorants, antiperspirants, and fragranced hygiene products is so ubiquitous and so deeply ingrained in human history, the social perception of fragrance-modified body odor may deeply influence a person's judgments about an unknown other. Cultural expectations dictate the framework of body odor that one finds socially acceptable: are people expected to wear deodorant, or not to wear it? Should men or women wear heavy cologne, or is that considered offensive? In American society, the use of perfumes has been shown to modify attractiveness (Baron, 1981), influence perceived competence of potential job candidates (Baron, 1986), and increase the likelihood of helping behavior towards the perfume wearer (Guéguen, 2001). Additionally, several

European studies have shown that perfume increases the pleasantness and attractiveness of body odor (Allen, Havlíček, & Roberts, 2015; Lenochová et al., 2012). Cross-culturally, perfume has also been shown to modify the attitudes and behaviors of the perfume wearer, decreasing nervous movements (Higuchi, Shoji, Taguchi, & Hatayama, 2005) and increasing confidence (Roberts et al., 2009). Personal fragrance preferences are relatively stable over time (Roberts, Havlíček, & Petrie, 2013), and wearing a non-preferred perfume has even been shown to decrease social engagement for the wearer (Freyberg & Ahren, 2011). Clearly, perfumes are important in multiple aspects of social life.

In the remainder of this dissertation, I will refer often to the term *diplomatic odor*. I use this term to refer to the modified body odor an individual presents in public situations. Diplomatic odor is composed of all of the fragranced products that might influence a given individual's body odor on a typical day: not just perfume and deodorant or antiperspirant, but also the fragrances from clothing detergent, shampoo and conditioner, toothpaste, makeup and other hygiene products, soap, and other fragrance influences. Even for individuals who wear, for example, different fragrances for different occasions, the link between HLA type and fragrance preference (Milinski & Wedekind, 2001), combined with the stability of fragrance preferences over time (Roberts et al., 2013), suggests that these fragrances are likely to remain within a specific odor realm for each individual. Additionally, the term diplomatic odor encompasses body odor influences related to diet and personal habits, such as drinking, smoking, and exposure to pets. Many of the foods that odor donors are asked to eliminate in traditional body odor studies are culturally specific – curry, chili, aromatic and highly spiced foods – and therefore a number of cultural cues that might be present in diplomatic body odor are eliminated in these body odor samples. In contrast, I refer to body odor devoid of outside fragrances and exogenous odor modifications as *natural odor* based on normative conventions within the field (e.g., Sorokowska, Sorokowski, & Havlíček, 2016), though ironically, as one critic has pointed out, diplomatic odor may actually be the more "natural" of the two in our modern society. Because fragrance choices are idiosyncratic, and because fragrance reacts differently with each individual's skin and microflora, the nature of diplomatic odor may be as individual as a natural odor print.

Because diplomatic odor is so tightly linked both with both underlying genotype and with cultural background, I hypothesize in this dissertation that diplomatic odor is a relevant social signal which coveys personal information about an individual and can affect others' social judgments about them. Though the effect of fragrance on emotional chemosignals has not yet been explored, a handful of studies support the idea that fragranced body odor can be used as an individually identifiable odor (Allen et al., 2015; Lenochová et al., 2012; Sorokowska et al., 2016). The majority of these studies, however, fail to consider the full scope of odor influences involved in diplomatic odor, focusing instead on the effects of perfume or deodorant only. Further, most of these studies employ male odor donors and female perceivers. Though we know that mate selection is influenced by olfactory cues, we also know that olfactory cues can be used to communicate information between individuals of the same gender (Mutic et al., 2015; Woodward, Thompson, & Gangestad, 2015). Because of the dearth of information about intrasexual communication, I have chosen in the ensuing studies to focus entirely on female judgments of other females. Given the frequency with which females apparently assess male chemical signals for the purposes of mate choice, it seems unlikely that female intrasexual communication is devoid of the use of social olfactory cues.

The first study in this dissertation will address the likelihood that olfactory cues are communicated in real life social interactions. This study will assess the differences in social judgments made about unknown others based on their diplomatic odor and natural body odor, as well as comparing the novel method we developed for examining these questions to more traditional social olfactory methods. The second study presented herein will speak to the question of whether chemical information is available in the presence of perfume. As previously mentioned, it is still unknown whether emotional information can be perceived when the sender is wearing a fragrance. Though we do not directly address the perception of emotions, this study provides important insight into the influence of perfume on individual body odor. Additionally, it addresses the potential of body odor to affect social judgments in other modalities. The final study presented here deals with the influence of olfactory information in real life, multimodal judgments of others, assessing the role of diplomatic odor in predicting social judgments in a live interaction. Taken together, these studies provide insight into the role of diplomatic odor in ecologically relevant female intrasexual social judgments. My hope is that this dissertation brings to light the importance of considering diplomatic odor in future olfactory research, while illuminating the role of odor in our daily lives.

CHAPTER 2

SMELLING IS TELLING: HUMAN OLFACTORY CUES INFLUENCE SOCIAL JUDGMENTS

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Abstract

How does a person's smell affect others' impressions of them? Most body odor research is conducted using armpit sweat without perfume or deodorant, presented on *t*-shirts. Yet, in real life, perceivers encounter fragranced body odor, on whole bodies. Our participants wore blindfolds and earplugs and repeatedly smelled real people in live interactions, both wearing their normal deodorant and perfume ("diplomatic" odor) and without ("natural" odor). We assessed the reliability of social judgments based on such live interactions, and the relationships between live judgments and traditional *t*-shirt based judgments, and between natural- and diplomatic odor-based judgments. Raters' repeated live social judgments (e.g., friendliness, likeability) were highly consistent for both diplomatic and natural odor, and converged with judgments based on *t*-shirts. However, social judgments based on natural odor did not consistently predict social judgments based on diplomatic odor. Our results show that ecologically relevant olfactory cues inform social judgments.

1. Introduction

If you are sitting next to a stranger on the bus, what cues influence whether or not you strike up a conversation? Obviously, a person's physical appearance plays an important role (Gunaydin et al. 2012; Tabak and Zayas 2012; Willis and Todorov 2006). But what role, if any, does olfactory information play? Research shows that natural body odor informs social judgments about health (Buljubasic & Buchbauer, 2014; Olsson et al., 2014), emotional state (Chen & Haviland-Jones, 2000; de Groot, Smeets, Kaldewaij, Duijndam, & Semin, 2012; Semin, 2015), and gender and sexual orientation (Lübke, Hoenen, & Pause, 2012; Martins et al., 2005). However, the traditional methodological approach to social olfactory research bears little resemblance to the way olfactory cues are encountered in real life. In the majority of social olfactory studies, perceivers make judgments based on axillary (armpit) sweat collected on *t*-shirts or cotton pads and presented via bags, vials, jars, or olfactometers. In contrast, in actual interactions, perceivers encounter body odor not from the armpit at close range, but from the entire body, at a socially acceptable distance. Moreover, traditional social olfactory studies focus on what we call *natural odor,* which is collected by having participants undergo a *washout* period during which they modify their hygiene, dietary, and habitual practices to eliminate all outside sources of odor. In everyday interactions, however, perceivers typically encounter a person's *diplomatic odor*, which is natural body odor modified by fragranced products, deodorants, dietary choices, and personal habits.

In the present research, our goal was to develop a paradigm that would allow us to assess social olfactory judgments as encountered in everyday interactions—

based on the whole body, with people wearing diplomatic odors. We aimed to compare this *live*, *diplomatic* approach with both a *live*, *natural* odor approach, and the traditional approach using body odors collected on *t*-shirts. Although much research on social olfaction has focused on judgments of opposite-gendered partners, here we focused on the role of olfactory cues in more commonplace social judgments of same-sex partners that do not involve mating choice motivation.

From disembodied odor samples to whole-body olfactory information. Is an axillary sweat sample, as employed in classical social olfactory research, a sufficient representative of the odor signature of an entire person? Several lines of evidence suggest not. Humans secrete distinctive odors from different areas of the body (Gallagher et al., 2008). Apocrine glands, concentrated in the axilla, groin, and feet, produce secretions that are heavily involved in the production of body odor (Shelley, Hurley, & Nichols, 1953). However, eccrine sweat, produced by glands distributed all over the body and concentrated in the forehead, hands, and feet, also contributes to body odor (Kippenberger et al. 2012; Penn et al. 2007). Even earwax (Prokop-Prigge et al. 2014) and breath can communicate a variety of signals (Buljubasic and Buchbauer 2014; Doty et al. 1978; Minami et al. 1989). In real interactions, the likelihood of directly smelling the axilla of another person—especially a stranger or acquaintance—is very low. Rather, perceivers encounter odor from all over the body, and this more complex odor profile may affect social judgments differently.

From natural odor to diplomatic odor. An important consideration, and motivation for the present work, is that traditional social olfactory studies employ samples of "natural," unadulterated sweat that are devoid of outside fragrances (see Havlíček et al. 2011). However, in most social interactions, perceivers encounter people wearing deodorant, which masks the smell of axillary sweat, or antiperspirant, which blocks the secretion of eccrine sweat (Draelos 2001). Additionally, people commonly wear perfume or cologne, which affects perceptions of attractiveness (Kirk-Smith and Booth 1987; Lenochová et al. 2012) and competence (Baron 1986), and impairs the ability to discriminate between individuals (Allen et al. 2015). Further, even if a person does not use perfume or cologne, most hygiene products (shampoo, clothing detergent, etc.) contain some fragrance. Finally, day-to-day odor is influenced by dietary choices (Fialová et al. 2016; Havlíček and Lenochova 2006), which are also routinely regulated in classical olfactory research.

To date, little attention has been given to the role of diplomatic odor in social judgments. One study (Sorokowska et al. 2016) suggested that diplomatic odor modifies social judgments. However, this study employed the classical approach of collecting axillary sweat on cotton pads, and participants were still required to modify their diets.

Present research. How do people use olfactory cues in ecologically relevant social interactions? We developed a novel paradigm to assess social judgments based on olfactory cues conveyed by the whole body in a live interaction. Blindfolded, earplugged *raters* made social judgments about the body odor of an unknown *donor*, seated beside them for 1 minute. Although raters judged between 4 and 10 different donors, we led them to believe they were judging twice as many unique donors. In reality, they judged each donor twice. This allowed us to assess the extent to which each rater showed consistent social preferences across exposures, based on odor alone.

In study 1, donors wore their diplomatic odor (i.e., with no changes to their regular use of hygiene products or diet). In study 2, we aimed to replicate the results of study 1, and to assess the extent to which social judgments based on diplomatic odor converged with those based on natural body odor. We also aimed to assess the extent to which social judgments based on live, whole body odor converged with those based on odor collected on *t*-shirts.

Our predictions for our first aim were clear. Given that perceivers are adept at making a variety of social judgments based on olfactory cues presented with the traditional approach, we hypothesized that people would make consistent social judgments based on diplomatic odor as well as natural odor, when such cues were encountered in a live interaction.

Our predictions for aim 2 were less clear, given the scarcity of research focusing on diplomatic odor and its relationship to natural odor. The extant literature points to two possibilities. Research suggesting that perfumes complement underlying genetic signals (Hammerli et al. 2012; Milinski and Wedekind 2001) would lead us to expect some convergence between judgments based on natural and diplomatic odor. However, research showing that antiperspirants block the excretion of body odor components (Draelos 2001), and that perfume modifies the attractiveness of body odors (Lenochová et al. 2012) and affects prosocial behavior (Guéguen 2001) suggests that judgments based on natural and diplomatic odor would show some divergence.

Finally, with regard to our third aim, we expected modest convergence between judgments based on the *t*-shirt approach and those based on the live, whole body paradigm. Live body odor contains information from all over the body, and is encountered at a social distance rather than up-close sniffing, possibly leading to divergence between these two modes of judgment. However, whole body odor also contains all of the information present on a *t*-shirt, and for this reason we would expect some convergence in these two modes of judgment.

2. Study 1: Methods

2.1. Participants. Forty heterosexual females, ages 18-35 years old, took part in the study as raters (n = 18) or donors (n = 22) (see Supplemental Materials for recruitment information). We were particularly interested in how perceivers use olfactory cues to inform social judgments in everyday platonic relationships (rather than in mate choice in opposite sex relationships). For this reason, we focused on heterosexual women.

We recruited the maximum possible number of participants for our space for each session (10 raters and 10 donors), though some participants failed to attend on the day of the study. Because adding raters also requires a full set of donors (ideally 10), it was neither fiscally nor temporally reasonable to add additional raters to our set. With the current sample, statistical power (1-β) for detecting an average (for the sample) within-person standardized association of 0.3 between round 1 judgments and round 2 judgments (two-tailed) was 99% (see Supplemental Materials for calculation of statistical power).

All protocols comply with the Declaration of Helsinki for Medical Research involving Human Subjects and were approved by the Cornell University Institutional Review Board (IRB). All participants were asked to read and sign the IRB-approved consent forms before beginning the study. Copies of our rating sheet and intake materials, along with all data and syntax for studies 1 and 2 can be found on Open Science Framework at osf.io/nbpy6.

2.2. Procedural overview. To ensure that raters and donors would not interact prior to the live rating session, each group was instructed to arrive at different locations. All participants completed an intake questionnaire regarding use of hygiene products/fragrances, stress, and menstrual cycle information (see Supplemental Materials). Participants were given group-specific instructions and then completed the live judgment task in their respective role. Instructions and procedures for raters and donors are described in detail in the next sections.

During the live olfactory judgment task (see Figure 1), each rater sat alone in a room. To isolate olfactory perception, raters wore earplugs and a blindfold. Each trial consisted of the following events: a donor entered the room, crossed in front of the rater to reach a chair placed directly beside her, sat for 1 minute, then crossed in front of the rater again while leaving the room. The rater had a 3-minute period in which to make a series of judgments based on the donor's odor, using provided questionnaires (described below). Unbeknownst to raters, each donor made two visits: every donor visited every rater once in a randomized order (round 1), raters and donors were allowed a 5-minute break, and then donors visited each rater a second time (round 2) in a new randomized order. During the break, experimenters interviewed participants to ensure that both raters and donors were adhering to the instructions.

2.3. Procedures for raters. Raters were told that they would smell 20 donors (easily twice the real number), to disguise the fact that they would be receiving repeat visits from each donor. Experimenters described the trial structure, and raters were then told to set their cell phones to vibrate, in order to receive messages from the experimenter signaling the beginning and end of each trial. Experimenters distributed blindfolds, ear plugs, and rating sheets, then led each rater to an individual room, where she was instructed to await the message signaling the start of the experiment (a ten-minute wait to allow olfactory adaptation to the room). Raters were told to avoid any verbal or physical interaction with donors. Experimenters entered each room to alert raters when it was time for the break; raters and donors were escorted to separate bathrooms if use was necessary.

2.4. Procedures for donors. Because we did not want donors to modify their diplomatic odor in any way, we did not inform them that they would be smelled by others until they arrived for the study. Research suggests that anxiety can affect social interpretation of body odor (Fialová and Havlíček 2012; Prehn-Kristensen et al. 2009), so rather than telling donors that raters were judging them on social parameters, we told them that raters were trying to guess their gender. Each donor received a unique travel map with the order of rooms to visit, and a small kitchen timer. During each trial (i.e., each visit), donors were told to start their 1-minute timer when opening the door, then to cross in front of the rater and sit beside her until their timer went off, at which point they would cross in front of the rater again, exit the room, and close the door. Donors were told to remain anonymous and avoid any verbal or physical interaction with raters. Donors traveled to the next room on their map during the 3-minute break between visits. Experimenters in the hallways announced the beginning of each round of trials, after texting raters to replace their blindfolds.

Figure 1. Photographic depiction of the set up for the live olfactory judgment paradigm. Rater is seated on the right, wearing blindfold and ear plugs and holding ratings sheets. Donor is seated on the left, holding a kitchen timer. Arrows reflect the donor's path on entry and exit.

2.5. Interpersonal judgments. After each trial, raters made a total of 11 judgments. We included 3 questions to assess common olfactory dimensions: pleasantness (*"How pleasant was this person's smell?"*), intensity (*"How intense was this person's smell?"*), and familiarity (*"How familiar was the smell of the person who just sat next to you?"*) (Jacob et al. 2002; Pause 2012; Prehn-Kristensen et al.

2009). Raters also completed 3 questions to assess judgments of interpersonal liking and friendliness ("*How likely would you be to have a conversation with [this person]?*", "*If you had to sit next to this person every day, it would be...*", *"How friendly was this person's smell?"*(Gunaydin et al. 2016)), and 3 questions to assess similarity to self ("*How similar was this person's smell to your own smell?*"), best female friend ("*How similar was this person's smell to the smell of your closest female friend?*"), and best male friend. Each judgment was made on a 100-mm visual analog scale with the ends labeled as "*not at all*" and "*very much*," depending on the question. Raters also answered 2 binary questions that were included to obfuscate the fact that all donors were female (*How would you classify this person's gender?"*) and to disguise repeat visits (*"Do you think you have smelled this person before?"*). Finally, we included an open-ended question ("*Is there anything else you would like to note about the smell of the person who just sat next to you?*").

Examination of zero order correlations showed that four questions that tap into liking (odor pleasantness, friendliness, willingness to sit by that person every day, and likelihood of having a conversation with that person) were highly correlated with one another (correlations ranged from .67 to .83 for round 1 and from .65 to .88 for round 2) but only weakly to moderately correlated with each of the similarity items (correlations ranged from .02 to .42 for round 1 and .14 to .48 for round 2). We therefore created a composite score for the four liking questions. This aggregate liking measure was highly reliable as indicated by Cronbach's alpha (α), computed for each donor and round separately. For study 1, αs for the aggregate liking measure ranged from .58-.99, *M*s ranged from 37.5-71.79 mm, and *SD*s ranged from 8.12-27.78 mm.

For study 2, αs ranged from .59-.96, with *M*s ranging from 45.2-80.4 mm and *SD*s from 4.91-21.67 mm.

Next, we examined the zero order correlations among the three similarity judgments. Although similarity to self and similarity to closest female friend were highly correlated (r = .72 for round 1, r = .65 for round 2), similarity to closest male was moderately correlated with similarity to self (r = .34 for round 1, r = .45 for round 2) and moderately correlated with similarity to female friend (r = .14 for round 1, r = .30 for round 2). Given the varied strength of correlations among similarity judgments, we did not compute an aggregate for the similarity questions and report results for the individual judgments.

2.6. Data analytic strategy.

2.6.1. Main analyses. Given the nested nature of the data (i.e., donors were nested within raters), we used multilevel models (MLMs) with a restricted maximum likelihood estimation (Hayes, 2006).

To test whether round 1 live, whole body judgments predicted round 2 live, whole body judgments, a series of MLMs (one for each judgment) were performed with round 2 responses as the dependent variable and round 1 responses as the fixed predictor. We treated the intercept as a random effect at the level of the rater for all the models, and as a fixed effect at the level of donor (see Supplemental Materials for details regarding model specification). To facilitate the interpretation of the results, prior to performing the MLM analyses, the individual judgments as well as the aggregate liking measure within each of the two rounds were converted to standardized scores (z scores). The aggregate liking score was computed using raw (unstandardized) data prior to standardization.

2.6.2. Correcting for multiple comparisons. Raters made a total of 10 judgments. Of these, four were highly correlated (discussed in the section *Interpersonal judgments*), and therefore aggregated to create an overall measure of liking, leaving us with a total of 6 distinct judgments. We applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our p value cutoff is .0083 (.05/6 tests) to reflect this correction.

2.6.3. Procedural variables. Participants were run in 3 different groups. Group 1 had 5 raters and 4 donors, group 2 had 7 raters and 10 donors, and group 3 had 6 raters and 8 donors. We therefore tested to see if our conclusions varied significantly across groups. To do so, we added a categorical variable reflecting group to our MLMs and tested for the effect of group, and its interaction with round 1 judgments. Group did not have a significant effect on any of our judgments (ps ranged from .101 to .956), nor did it interact with round 1 judgments (ps ranged from .022 to .966). As our conclusions did not depend on group, we dropped it from the model.

3. Study 1: Results

On average across all raters, round 1 judgments of interpersonal liking based on live, whole body diplomatic odor, as reflected by the aggregate liking measure, significantly predicted round 2 judgments of interpersonal liking ($\beta = .55$, $p < .001$; Figure 2). As shown in Table 1, consistency in olfactory-based judgments across rounds was observed for each of the individual judgments of liking (rows 3 to 6), judgments of similarity (rows 9-11), and judgment of intensity (row 7). The only judgment to show poor consistency across the two rounds was familiarity (row 8).

Table 1. Do raters make consistent social judgments based on live, whole body diplomatic odor? Level-1 coefficients representing the extent to which a given rater's round 1 judgments predict her round 2 judgments for the same donor.

Question	β	SE	*df*	*p*	95% CI
Liking (aggregate)	.55	.07	133.67	<.001	[.41, .69]
Pleasant Odor+	.50	.07	134.12	<.001	[.36, .64]
Friendly+	.42	.08	133.46	<.001	[.27, .57]
Have a conversation?+	.57	.07	99.8	<.001	[.43, .71]
Pleasant to sit by+	.47	.07	135.53	<.001	[.32, .61]
Intense Odor	.55	.07	131.25	<.001	[.41, .68]
Familiar	.07	.09	129.18	.467	[–.11, .24]
Similar to own smell	.42	.08	134.26	<.001	[.27, .57]
Similar to female best friend	.39	.07	132.24	<.001	[.25, .52]
Similar to male best friend	.47	.07	125.98	<.001	[.32, .61]

Notes. Values are based on standardized scores (z scores). β represents the level 1 slope coefficient predicting judgment in round 2 from judgment in round 1. Positive coefficients represent greater within-rater consistency in olfactory-based judgments across rounds. Because we performed 10 different analyses, with 4 of those included in our aggregate, we applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our *p* value cutoff is .0083 (.05/6) to reflect this correction. + Denotes variables included in the interpersonal liking aggregate.

3.1. Assessing the role of rater effects. To what extent is the observed consistency in olfactory-based judgments driven by particular raters? As shown in Figure 2, within-person consistency in social olfactory judgments was observed for the overwhelming majority of raters. Specifically, 94% of the sample showed some evidence of consistency, which we assessed by identifying the number of raters with a positive (i.e., non-zero) within-person level-1 coefficient and computing the percentage of positive slopes in the sample.

3.2. Assessing the role of donor effects. To what extent is consistency in live, whole body olfactory-based judgments driven by the odors of particular donors (i.e., a donor effect)? In other words, perhaps some donors are consensually judged favorably based on odor cues, whereas others are judged unfavorably, and such donor effects give rise to within-rater consistency. Even though our analyses statistically control for donor effects in round 2 judgments, we conducted auxiliary analyses to provide a stringent control for possible donor effects. We reasoned that to the extent that consistency in olfactory-based judgments is the result of donor effects, then round 1 judgments for any given rater should predict round 2 judgments for a *different*, randomly selected rater. To test whether this was the case, we randomly paired raters (see Supplemental Materials for details), and then predicted each rater's round 2 judgments from their own round 1 judgment (*matched* data) as well as from a *different* rater's round 2 judgments (*mismatched* data). If there are no appreciable effects of donors, then the mismatched data should be a worse predictor of round 2 judgments than the matched data.

The results of these auxiliary analyses revealed evidence of donor effects, but critically that donor effects do not fully explain the within-person consistency in olfactory-cued judgments. Specifically, round 1 judgments of a randomly paired rater predicted round 2 judgments for the aggregate liking measure ($\beta = .22$, $p = .008$), willingness to sit by ($\beta = .23$, $p = .004$), and intensity ($\beta = .42$, $p < .001$) (see Table S4 in Supplemental Materials). These results suggest that some donors were consensually evaluated more favorably, and more intensely, than other donors. However, critically, for all judgments for which we had observed significant within-person consistency, raters' *own* round 1 judgments (matched data) were significantly stronger predictors of round 2 judgments than a different rater's round 1 judgments (mismatched data). To illustrate, for the matched data, the level-1 (within person) slope coefficient representing own round 1 judgments predicting the same raters' round 2 judgments was .55, $p < .001$. In contrast, for the mismatched data, the level-1 slope coefficient was .22, $p < .008$. The difference in magnitude of these level-1 coefficients was statistically significant ($\beta = .41$, $p < .001$; see Supplemental Materials). Moreover, when both matched and mismatched round 1 judgments were entered simultaneously as level-1 predictors, raters' own data continued to significantly predict round 2 judgments ($\beta = .52$, $p < .001$), but mismatched data did not ($\beta = .08$, $p = .250$) (see Supplemental Materials for full description of results).

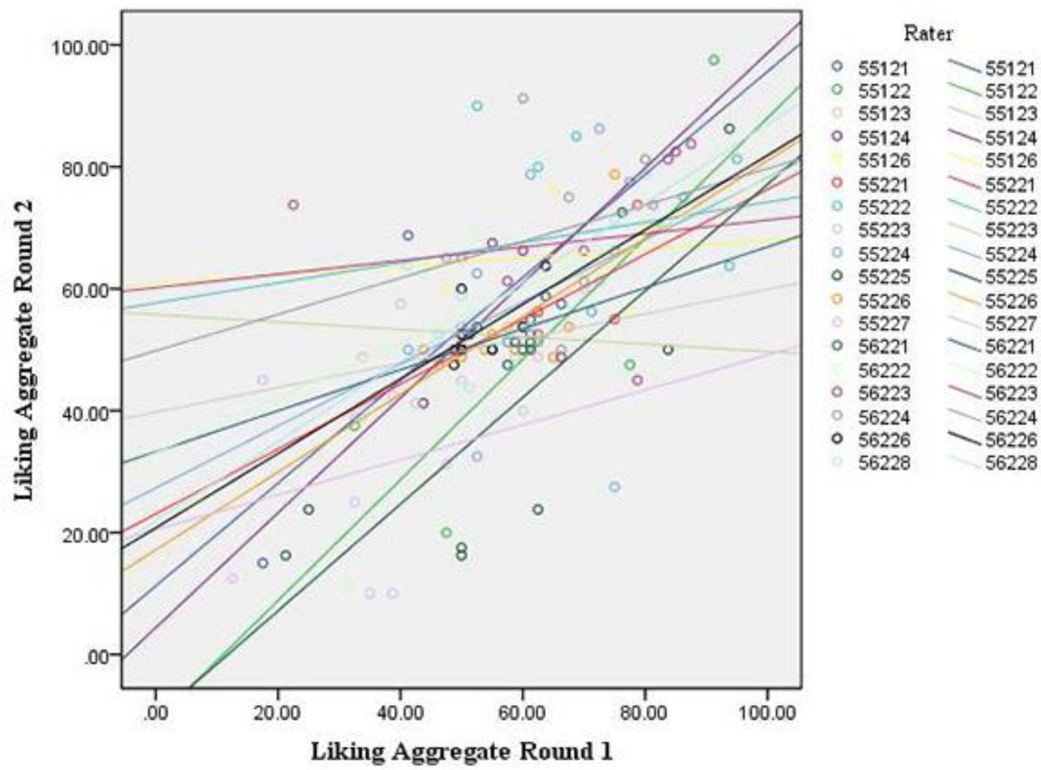

Figure 2. Scatterplot showing consistency, for each rater, in judgments based on diplomatic odor in the live olfactory judgment paradigm. Values are based on unstandardized scores (range 00-mm to 100-mm). Each point denotes the aggregate liking judgment made by a specific rater for a single donor at round 1 (x-axis) and again at round 2 (y-axis). Lines represent the relationship, for each rater, between judgments for round 1 and for round 2. Positive slopes indicate greater consistency for a given rater.

4. Study 2: Methods

Study 1 provides evidence that perceivers are able to make olfactory-based judgments in semi-realistic interactions. Study 2 aimed to replicate this finding, and extend the work in two ways. First, we compared judgments based on our live, whole body paradigm to judgments based on a classical *t*-shirt odor collection method. Second, we aimed to examine the extent to which judgments based on diplomatic odor converge or diverge from judgments based on natural body odor: does liking someone's natural body odor predict that you will also like their diplomatic body odor?

4.1. Participants. 35 self-reported heterosexual women, ages 18-35 (mean age 22.1 years) participated as raters (*n*=17) or donors (*n*=18) (see Supplemental Materials for recruitment details). With the current sample, statistical power (1-β) for detecting an average (for the sample) within-person standardized association of 0.3 between round 1 and round 2 judgments was > 99% and the power to detect a difference of 0.3 in consistency between diplomatic and natural and between live vs. *t*-shirt approaches was 78% (see Supplemental Materials for calculation of statistical power).

All protocols comply with the Declaration of Helsinki for Medical Research involving Human Subjects and were approved by the Cornell University Institutional Review Board (IRB). All participants were asked to read and sign the IRB-approved consent forms before beginning the study.

4.2. Procedural overview. Donors and raters participated in 2 sessions, separated by 1 week. For the "natural" odor session, we asked donors to prepare by doing a 2-day washout in the style of traditional body odor studies (Havlíček et al.

2011). For the "diplomatic" session, we asked them to come wearing their usual diplomatic odor. At both sessions, we also collected *t*-shirts from donors (see below).

The study took place across 2 consecutive Saturdays with participants assigned to either the morning (AM) or afternoon (PM) group depending on their availability. To ensure that order of odor type was counterbalanced, the morning raters smelled natural body odor the first week and diplomatic odor the second week, and afternoon raters smelled diplomatic the first week and natural the second. Group 1 (morning) had 10 raters and 9 donors the first week and 9 raters and donors the second week, while group 2 (afternoon) had 5 raters and 9 donors the first week, and 6 raters and 7 donors the second week.

The study consisted of 3 distinct parts:

4.2.1. Pre-study visit. Participants arrived at the lab to sign consent forms, and, if they were donors, to receive *t*-shirts and supplies for their washout. Donors were again misled to believe that we were interested in whether raters could guess their gender, and raters were again misled that they would be smelling 20 donors.

4.2.2. Washout and odor collection. In preparation for collecting natural body odor, we asked participants to undergo a 2-day washout following established protocols (Zhou and Chen, 2009). The day before each session, participants donned a *t*-shirt in the morning after their shower (natural condition), and wore it for at least 12 hours. In the natural odor condition, they continued following all fragrance, deodorant, and diet elimination rules. For the diplomatic condition, we asked them not to make any changes to their normal routine while wearing the *t*-shirt. Participants stored worn *t*-shirts in ziplock bags overnight in a freezer, then wore them to the lab the following day (see Supplemental Materials for details).

4.2.3. Testing sessions. The procedures for diplomatic and natural odor sessions were identical, and differed only in the preparations on the part of the donors prior to arriving at the testing session (see above). To assess social judgments based on the live, whole body olfactory paradigm, we used procedures and materials similar to those used in study 1. The one exception was the method used to notify donors and raters of the start and end of a trial. In study 2, we had donors knock loudly on the doors to raters' rooms before entering, and raters were alerted to the end of each trial by the beeping of donors' kitchen timers, rather than a text. We ensured that both noises were audible through the earplugs. Donors wore their shirts during the live sessions.

Following the live sessions, we asked donors to place their *t*-shirts in ziplock bags, which experimenters arbitrarily labeled 1-10. Raters remained in their testing rooms until notified by experimenters, then congregated in a single room with the labeled *t*-shirt bags and received a list with a unique randomized order in which to smell the shirts. For each *t*-shirt, raters (wearing gloves) were instructed to open the bag, take a single sniff, and close the bag again before making their ratings. We used identical rating sheets to those from the live ratings, to make comparison as straightforward as possible.

4.3. Data analytic strategy.

4.3.1. Main Analyses. Similar to study 1, data were nested, such that donors were nested within raters. To account for the nested nature of the data, we again used multilevel models (MLMs) with a restricted maximum likelihood estimation (Hayes 2006).

4.3.2. Testing consistency in live judgments. To test our first question of whether round 1 live, whole body judgments predicted round 2 live, whole body judgments, we followed the approach used in Study 1. We specified round 2 judgments as the dependent variable and round 1 judgments as the predictor. For all our models, we chose to use random intercepts at the level of rater and donor, but fixed slopes for both (see Supplemental Materials for details). To facilitate the interpretation of the results, prior to performing the MLM analyses, the individual judgments and the aggregate liking measure (which was computed using the raw, unstandardized judgments) were converted to standardized scores (z scores).

We also assessed whether consistency across rounds was moderated by odor type (natural or diplomatic). Accordingly, odor type as well as the odor type × round 1 judgment interaction were included as predictors in the model. None of the odor type × round 1 judgment interactions were statistically significant with the Bonferroni correction (See Table S7 in Supplemental Materials). Thus, for the sake of simplicity, we dropped odor type from the model (our conclusions do not change if odor type is kept in the model). For the interested reader, we present results for both odor types combined, as well as separately.

4.3.3. Testing convergence across live, whole body and t-shirt methodologies. To test our second question of whether live judgments predicted *t*-shirt based judgments, we computed the mean of the two rounds of live judgments and then standardized these mean scores. The mean of the live judgments was entered into the model as a fixed predictor, with *t*-shirt based judgments as our dependent variable. Similar to our first aim, we again tested if convergence across the two methodologies was moderated by odor type (natural vs. diplomatic) by entering odor type as well as the odor type × mean (of round 1 and round 2) live judgments interaction as predictors in the model. Odor type did not significantly moderate consistency between the two methodologies for any of the judgments (see Table S8 Supplemental Materials). We therefore dropped condition from the model. For the interested reader, we present results for both odor types combined, as well as separately.

4.3.4. Testing convergence across diplomatic and natural judgments. Finally, to test whether judgments based on natural odor predicted judgments based on diplomatic odor, we again used the mean of the two rounds of live judgments, and standardized these mean scores. We restructured the data file into a "long" format, "stacking" judgments based on *t*-shirts and live presentation methods. Our dependent variable was the mean judgment in the diplomatic odor condition, and the fixed predictor was the mean judgment in the natural odor condition. We also examined whether convergence between judgments based on diplomatic and natural odor varied depending on presentation method by including method (live vs. *t*-shirt based) as a predictor, along with the method and mean natural odor judgments interaction. Because presentation method did not moderate the relationship between natural and diplomatic odor judgments (see Supplemental Materials), we dropped it from the model. However, similar to the two other aims, for the interested reader, we present results for both presentation methods combined, as well as separately.

4.3.5. Procedural variables. Participants were run in 2 different groups (morning or afternoon). We therefore tested to see if our conclusions varied significantly across groups. To do so, we added a categorical variable reflecting group to our MLMs and tested for the effect of group, and its interaction with round 1 judgments. We found no statistically significant effects of, or interactions with group (see Supplemental Materials for details). As our conclusions did not depend on group, we dropped it from the model.

4.3.6. Correcting for multiple comparisons. As in study 1, we ran a total of 10 analyses with 4 variables included in an aggregate score, and applied a Bonferroni correction to ensure that our overall experiment-wise alpha remained at .05. Our *p* value cutoff was .0083 to reflect this correction (.05/6).

5. Study 2: Results

5.1. Reliability of live olfactory-based judgments. Replicating the results of Study 1, we observed substantial consistency in olfactory judgments based on live, whole body diplomatic odor. On average across all raters, round 1 judgments of interpersonal liking, as reflected by the aggregate liking score, significantly predicted round 2 judgments of interpersonal liking for diplomatic odor ($\beta = .56$, $p < .001$; see Figure 3, top panel). We also observed consistency in olfactory-based live, whole body judgments across rounds for each of the individual judgments of liking, of similarity (e.g., to self, female best friend, and male best friend), of intensity, and of familiarity (see Table 2).

Extending the findings from Study 1, raters also showed remarkable consistency in olfactory judgments based on live, whole body natural odor. On average, round 1 live judgments of interpersonal liking, as reflected by the liking aggregate, predicted round 2 live judgments of interpersonal liking for natural body odor ($\beta = .31$, $p < .001$; see Figure 3, bottom panel). Moreover, we observed consistency in olfactory judgments based on live, whole body natural odor for each of the individual judgments of liking and similarity, but not for judgments of intensity or familiarity (see Table 2).

It is worth noting that the consistency in olfactory judgments between diplomatic and natural odor cues did not differ significantly on any judgment (See Table S7 in Supplemental Materials). However, the lack of statistically significant differences should be interpreted cautiously. Indeed, the interaction term approached statistical significance for the liking aggregate ($p = .028$) and familiarity judgment ($p = .01$). Moreover, a visual inspection of the level-1 coefficients reported in Table 2 reveals that on 8 of the 10 judgments, judgments based on natural odor showed weaker consistency than judgments based on diplomatic odor.

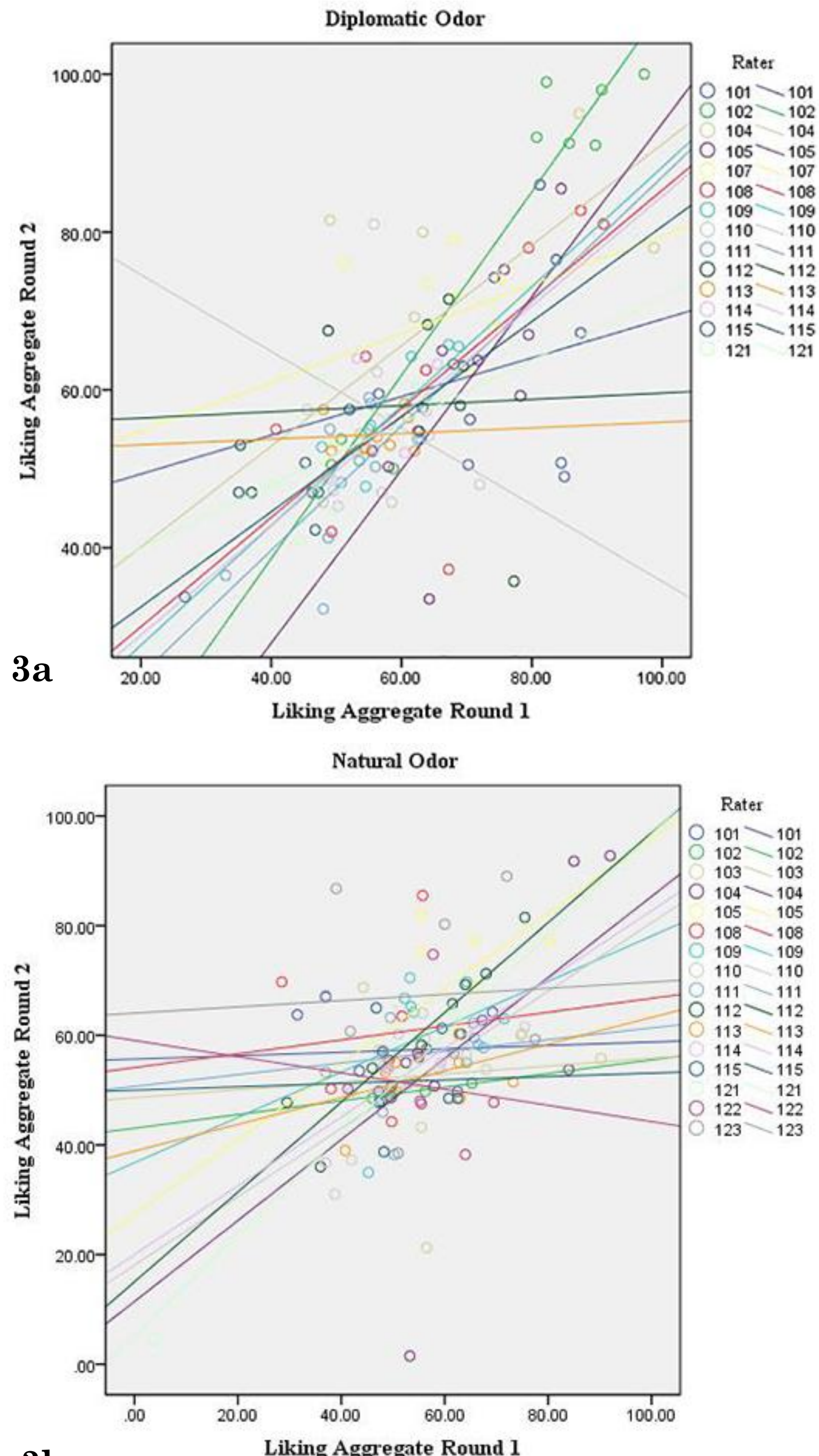

Figure 3. Scatterplots showing consistency, for each rater, in judgments based on diplomatic odor (Fig. 3a) and natural odor (Fig. 3b) in the live olfactory judgment paradigm. Values are based on unstandardized scores (range 00-mm to 100-mm). Each

point denotes the aggregate liking judgment made by a specific rater for a single donor at round 1 (x-axis) and again at round 2 (y-axis). Lines represent the relationship, for each rater, between judgments for round 1 and for round 2. Positive slopes indicate greater consistency for a given rater.

Table 2. Do raters make consistent social judgments based on live, whole body odor? Level-1 coefficients representing the extent to which a given rater's round 1 judgments of a particular donor predict her round 2 judgments of the same donor.

Question		β	SE	*df*	*p*	95% CI
Liking (aggregate)						
	Diplomatic	.56	.07	110.42	<.001	[.41, .70]
	Natural	.31	.08	123.22	<.001	[.16, .47]
	Combined	.47	.05	246.63	<.001	[.37, .57]
Pleasant Odor+						
	Diplomatic	.60	.07	101.33	<.001	[.46, .75]
	Natural	.25	.07	116.58	<.001	[.11, .40]
	Combined	.45	.05	253.68	<.001	[.34, .55]
Friendly+						
	Diplomatic	.46	.08	121.75	<.001	[.31, .61]
	Natural	.32	.08	126.02	<.001	[.16, .48]
	Combined	.43	.05	23.08	<.001	[.33, .54]
Have a conversation?+						
	Diplomatic	.52	.07	102.58	<.001	[.38, .66]
	Natural	.27	.08	12.36	<.001	[.11, .43]
	Combined	.41	.05	245.96	<.001	[.3, .51]
Pleasant to sit by+						
	Diplomatic	.44	.08	12.09	<.001	[.28, .60]
	Natural	.32	.08	124.67	<.001	[.17, .47]
	Combined	.43	.05	253.38	<.001	[.32, .53]
Intense Odor						
	Diplomatic	.40	.08	12.43	<.001	[.24, .56]
	Natural	.17	.09	127.01	.053	[.00, .34]
	Combined	.37	.06	244.86	<.001	[.26, .48]
Familiar						
	Diplomatic	.24	.08	119.25	.002	[.09, .39]
	Natural	.08	.08	122.48	.282	[–.07, .24]
	Combined	.13	.06	246.59	.033	[.01, .24]
Similar to own smell						
	Diplomatic	.23	.08	122.75	.006	[.07, .39]
	Natural	.28	.07	123.48	<.001	[.14, .43]
	Combined	.32	.05	252.83	<.001	[.21, .43]
Similar to female best friend						
	Diplomatic	.33	.09	121.41	<.001	[.16, .50]
	Natural	.45	.07	123.80	<.001	[.31, .60]
	Combined	.39	.06	252.76	<.001	[.28, .5]
Similar to male best friend						
	Diplomatic	.41	.08	121.70	<.001	[.24, .57]
	Natural	.32	.08	112.57	<.001	[.15, .49]
	Combined	.35	.06	244.15	<.001	[.23, .46]

Notes. Values are based on standardized scores (z scores). β represents the level 1 slope coefficient predicting round 2 judgment from round 1 judgment. Positive coefficients represent greater within-rater consistency in olfactory-based judgments across rounds. Because we performed 10 different analyses, with 4 of those included in our aggregate, we applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our *p* value cutoff is .0083 (.05/6) to reflect this correction. + Denotes variables included in the liking aggregate.

5.2. Assessing the role of rater effects. Similar to study 1, the within-person consistency in social olfactory judgments based on diplomatic odor was observed for the overwhelming majority of the raters. This was also the case for judgments based on natural body odor. Specifically, we identified the number of raters with a positive (i.e., non-zero) within-person level-1 coefficient and computed the percentage of positive slopes in the sample. 93% of raters showed evidence of consistency in their social judgments based on diplomatic odor cues, and 94% of raters showed evidence of consistency in social judgments based on natural odor cues.

5.3. Assessing the role of donor effects. Similar to study 1, we conducted auxiliary analyses to provide a stringent control for the possibility that the observed within-person consistency in olfactory judgments were driven by some donors being consensually judged more favorably than other donors (i.e., donor effect). As a reminder, we reasoned that to the extent that consistency in olfactory-based judgments is the result of donor effects, then round 1 judgments for any given rater should predict round 2 judgments for a *different*, randomly selected rater.

The results of the auxiliary analyses show that there are donor effects, but importantly, donor effects did not fully account for the within-person consistency in olfactory-cued judgments. Specifically, round 1 judgments of a randomly paired rater predicted round 2 judgments for liking, as reflected by the aggregate liking measure (β = .18, p = .002), each of its individual components (βs range from .16 to .34, ps range from <.001 to .008; see Table S10 in Supplemental Materials for details), and intensity (β = .38, p < .001). These results suggest that some donors were consensually evaluated more favorably and more intensely than other donors. However, critically, for all judgments for which we had observed consistency, raters' *own* round 1 judgments (matched data) were significantly stronger predictors of round 2 judgments, than a different rater's round 1 judgments (mismatched data). Specifically, with regard to the liking aggregate, the level-1 slope coefficient for raters' own round 1 judgments predicting the same raters' round 2 judgments was .47, $p < .001$. In contrast, for the mismatched data, the level-1 slope coefficient was .18, $p = .002$. The difference in the level-1 coefficient, as reflected by a round 1 judgment × match interaction was highly statistically significant ($\beta = .25$, $p < .001$). Moreover, when both matched and mismatched round 1 judgments were entered simultaneously as level-1 predictors, raters' own data continued to significantly predict round 2 judgments ($\beta = .45$, $p < .001$), but mismatched data did not ($\beta = .10$, $p = .062$) (see Supplemental Materials).

5.4. Do judgments based on live, whole body odor predict judgments based on odor samples collected on *t*-shirts? Overall, judgments of interpersonal liking based on live, whole body odor moderately predicted judgments of interpersonal liking presented on *t*-shirts (for the liking aggregate: $\beta = .29$, $p < .001$; see Table 3). Odor type did not significantly moderate this effect (see Table S8 in Supplemental Materials), with judgments across the two methodologies showing similar magnitude of convergence for the liking aggregate measure for both diplomatic ($\beta = .25$, $p < .007$) and natural odors ($\beta = .28$, $p < .002$).

Table 3. Do judgments based on live, whole body odor predict t-shirt based judgments? Level-1 coefficients representing the extent to which a given rater's live, whole body judgments of a particular donor predict t-shirt based judgments of the same donor.

Question		β	SE	*df*	*p*	95% CI
Liking (aggregate)						
	Diplomatic	.26	.09	88.76	.005	[.08, .44]
	Natural	.22	.09	127.23	.019	[.04, .41]
	Combined	.29	.06	219.12	<.001	[.17, .41]
Pleasant Odor+						
	Diplomatic	.17	.09	114.86	.070	[–.01, .36]
	Natural	.17	.09	123.55	.063	[–.01, .35]
	Combined	.20	.06	252.80	.001	[.08, .32]
Friendly+						
	Diplomatic	.20	.09	104.74	.040	[.01, .38]
	Natural	.32	.09	106.05	.001	[.15, .49]
	Combined	.28	.06	234.87	<.001	[.16, .40]
Have a conversation?+						
	Diplomatic	.37	.09	72.33	<.001	[.18, .56]
	Natural	.31	.09	51.14	.001	[.14, .48]
	Combined	.33	.07	181.02	<.001	[.20, .45]
Pleasant to sit by+						
	Diplomatic	.33	.10	81.98	.001	[.14, .52]
	Natural	.19	.09	123.73	.033	[.02, .37]
	Combined	.27	.06	237.27	<.001	[.15, .40]
Intense Odor						
	Diplomatic	.08	.10	111.24	.431	[–.11, .27]
	Natural	.26	.10	83.88	.008	[.07, .45]
	Combined	.29	.07	231.70	<.001	[.17, .42]
Familiar						
	Diplomatic	.41	.09	81.08	<.001	[.23, .58]
	Natural	.23	.09	73.41	.014	[.05, .41]
	Combined	.30	.06	119.54	<.001	[.17, .43]
Similar to own smell						
	Diplomatic	.19	.09	107.52	.042	[.01, .37]
	Natural	.19	.08	128.94	.027	[.02, .35]
	Combined	.19	.06	251.13	.002	[.07, .30]
Similar to female best friend						
	Diplomatic	.35	.09	10.70	<.001	[.18, .53]
	Natural	.24	.09	125.01	.006	[.07, .41]
	Combined	.26	.06	244.80	<.001	[.14, .38]
Similar to male best friend						
	Diplomatic	.17	.08	121.53	.027	[.02, .33]
	Natural	.48	.08	85.24	<.001	[.33, .64]
	Combined	.33	.06	248.51	<.001	[.22, .44]

Notes. Values are based on standardized scores (z scores). β represents the level 1 slope coefficient predicting *t*-shirt based judgments from mean live judgments (averaged across rounds 1 and 2). Positive coefficients represent greater within-rater consistency in olfactory-based judgments across presentation types. Because we performed 10 different analyses, with 4 of those included in our aggregate, we applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our *p* value cutoff is .0083 (.05/6) to reflect this correction. + Denotes variables included in the interpersonal liking aggregate.

5.5. Do judgments based on natural odor predict judgments based on diplomatic odor? Does liking someone's natural body odor predict that you will also like their diplomatic body odor? Overall, correspondence between judgments based on natural odor and those based on diplomatic odor was weak. For our primary liking aggregate measure, judgments based on natural odor did not significantly predict judgments based on diplomatic odor ($\beta = .12$, $p = .099$). We ran a larger model testing for interactions between session and whether ratings were made during live sessions or based on *t*-shirts. We did find some differences based on both session and presentation method for a few of our variables (see Supplemental Materials for discussion).

Table 4. Do judgments based on natural odor predict judgments based on diplomatic odor? Level-1 coefficients representing the extent to which a given rater's judgments based on the natural body odor of a particular donor predict her judgments based on the same donor's diplomatic body odor.

Question		β	SE	*df*	*p*	95% CI
Liking (aggregate)						
	Live	.16	.10	104.2	.125	[-.04, .36]
	t-shirt	.10	.10	105.49	.314	[-.10, .30]
	Combined	.12	.07	213.67	.099	[.02, .27]
Pleasant Odor+						
	Live	.10	.10	102.83	.287	[-.09, .31]
	t-shirt	.13	.10	105.62	.207	[-.07, .33]
	Combined	.11	.07	209.16	.148	[-.04, .25]
Friendly+						
	Live	.10	.09	104.52	.279	[-.08, .29]
	t-shirt	.08	.10	103.14	.419	[-.11, .27]
	Combined	.08	.07	213.7	.224	[-.05, .22]
Have a conversation?+						
	Live	.19	.09	98.65	.040	[.01, .38]
	t-shirt	.26	.09	106.43	.005	[.08, .45]
	Combined	.23	.07	214.16	.001	[.10, .36]
Pleasant to sit by+						
	Live	.17	.09	10.09	.039	[.01, .35]
	t-shirt	-.04	.10	105.15	.703	[-.23, .15]
	Combined	.06	.07	212.09	.385	[-.07, .19]
Intense Odor						
	Live	.15	.08	58.82	.047	[.00, .31]
	t-shirt	.22	.08	100.52	.008	[.06, .37]
	Combined	.28	.06	199.9	<.001	[.16, .39]
Familiar						
	Live	.34	.09	98.52	<.001	[.16, .51]
	t-shirt	.11	.09	100.09	.229	[-.07, .29]
	Combined	.12	.06	204.78	.048	[.00, .25]
Similar to own smell						
	Live	.17	.09	105.77	.080	[-.02, .35]
	t-shirt	.32	.10	86.80	.001	[.13, .51]
	Combined	.19	.07	213.53	.007	[.05, .32]
Similar to female best friend						
	Live	.17	.09	104.49	.045	[.00, .34]
	t-shirt	.24	.09	100.98	.006	[.07, .43]
	Combined	.14	.06	209.47	.021	[.02, .26]
Similar to male best friend						
	Live	.14	.11	90.69	.216	[-.08, .35]
	t-shirt	.18	.10	106.46	.085	[-.02, .35]
	Combined	.11	.08	19.45	.146	[-.04, .27]

Notes. Values are based on standardized scores (z scores). β represents the level 1 slope coefficient mean diplomatic odor judgments from mean natural odor judgments (mean of round 1 and 2). Positive coefficients represent greater within-rater consistency across odor conditions. Because we performed 10 different analyses, with 4 of those included in our aggregate, we applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our *p* value cutoff is .0083 (.05/6) to reflect this correction. + Denotes variables included in the interpersonal liking aggregate.

6. General Discussion

Human social olfactory research has shown that body odor contains a number of powerful social cues. However, the majority of this research is based on perceivers making social judgments about axillary odor samples, presented on *t*-shirts or pads, collected from individuals who engaged in stringent practices to rid themselves of outside fragrance. In real life, however, body odor is encountered in the vastly different olfactory context of whole body odor with the products and habits that give rise to *diplomatic* scent.

We developed a paradigm that allowed raters to make social judgments of others based solely on their live, whole body odor at distances resembling typical social interactions. In study 1, raters made highly consistent olfactory-based social judgments based on others' diplomatic odor. Relying solely on olfactory cues, if a rater judged an unknown other to be friendly in a first meeting, the rater was also likely to judge this person favorably in a second meeting. In study 2, we replicated these findings, and extended them by showing that raters made highly consistent social judgments based on natural body odor, that our live, whole body approach converges with the traditional t-shirt approach, and that judgments based on diplomatic odor are weakly related to judgments based on natural odor.

The present work focuses on the influence of diplomatic odor in everyday social judgments. Our findings indicate that judgments of social partners based solely on olfactory cues reflect idiosyncratic preferences that rely on unique combinations of rater and donor. Research suggests that a person's olfactory preferences are driven both by genetics (Keller et al. 2007; Milinski and Wedekind 2001) and experience

(Balogh and Porter 1986; Davis and Porter 1991; Mennella et al. 2001). Social judgments based on diplomatic odor in particular are likely informed by preferences for fragrance components, and underlying genetic, dietary, and health information. The present findings suggest that perceivers use diplomatic odor to make social judgments about a person's friendliness and familiarity, driven by this plethora of genetic and experiential biases.

Interestingly, the relationship between judgments based on natural and diplomatic olfactory cues of the same individual was weak. Such findings are consistent with research showing the potential of perfumes and deodorants to change perception of body odor (Lenochova et al. 2012; Allen et al. 2015. The lack of congruency that we and others have observed between judgments of fragranced and natural body odor highlights the need to examine the extent to which phenomena observed with traditional samples of natural body odor – perception of fear signals or health information, for example – occur when people wear their typical diplomatic odor.

To the best of our knowledge, no study has compared how judgments based on olfactory cues presented on *t*-shirts relate to judgments of those same individuals in a live setting. We found that body odors presented on *t*-shirts were perceived similarly to live body odors. Given the large body of olfactory work using *t*-shirt based samples and other similar approaches, the present work provides important empirical validation of current social olfactory research methods.

6.1. Future directions. The present work shows the importance of olfactory information in shaping women's first impressions of other women in platonic interactions. In the context of mate selection, women typically attribute more importance to olfactory information than men (Havlicek et al. 2008; Herz and Inzlicht 2002). There is a general dearth of studies focusing on male perception of male body odor, though men are capable of perceiving social olfactory signals from other men (Chen and Haviland-Jones 2000). Future research should investigate the role of live, diplomatic odor on men's first impressions of other men.

Additionally, our study asked raters to make judgments based on odors collected on whole *t*-shirts, not just the axillary area as much previous research has done (e.g., Havlíček et al. 2011). Whole *t*-shirts present a different odor profile than axillary areas alone. Thus, future research should investigate the extent to which judgments of whole *t*-shirts converge with that of axillary-only samples.

Finally, in our live olfactory judgment paradigm, we isolated the olfactory cues by having raters wear earplugs and blindfolds. However, everyday dyadic interactions are multimodal, including visual, auditory, and a variety of behavioral and other cues, and are also bidirectional (Zayas et al. 2002). One possible direction for future research is to investigate the influence of olfactory cues – diplomatic or natural – in such rich, multimodal, and dynamic dyadic contexts.

6.2. Conclusion. Our study provides evidence that olfactory cues affect social judgments in realistic social interactions. We argue that, when examining these cues, outside odor influences such as hygiene and dietary choices should be considered. Given the plethora of cues that can be gleaned from traditional laboratory body odor samples, it is important to examine the extent to which perceivers are able to make such judgments in ecologically relevant settings. Our study suggests that natural and diplomatic odor are perceived differently, highlighting the importance of examining the effect of olfactory cues on social judgments in the context of normal fragrance and deodorant use. Here, we provide a first step towards answering these important questions.

References

Allen, C., Havlíček, J., & Roberts, S. C. (2015). Effect of fragrance use on discrimination of individual body odor. *Frontiers in Psychology*, *6*(August), 1–7. http://doi.org/10.3389/fpsyg.2015.01115

Balogh, R., & Porter, R. H. (1986). Olfactory preferences resulting from mere exposure in human neonates. *Infant Behavior and Development*, *9*(4), 395–401. http://doi.org/10.1016/0163-6383(86)90013-5

Baron, R. A. (1986). Self-Presentation in Job Interviews: When There Can Be "Too Much of a Good Thing." *Journal of Applied Social Psychology*, *16*(1), 16–28. http://doi.org/10.1111/j.1559-1816.1986.tb02275.x

Buljubasic, F., & Buchbauer, G. (2014). The scent of human diseases: A review on specific volatile organic compounds as diagnostic biomarkers. *Flavour and Fragrance Journal*, *30 (1)*(August 2014), 5–25. http://doi.org/http://dx.doi.org/10.1002/ffj.3219

Chen, D., & Haviland-Jones, J. (2000). Human olfactory communication of emotion. *Perceptual and Motor Skills*, *91*(3 Pt 1), 771–81. http://doi.org/10.2466/pms.2000.91.3.771

Davis, L. B., & Porter, R. H. (1991). Persistent effects of early odor exosure on human neonates. *Chem. Senses*, *16*(2), 169–174.

de Groot, J. H. B., Smeets, M. a M., Kaldewaij, A., Duijndam, M. J. a, & Semin, G. R. (2012). Chemosignals communicate human emotions. *Psychological Science*, *23*(11), 1417–24. http://doi.org/10.1177/0956797612445317

Doty, R. L., Ordnoff, M. M., Leyden, J., & Kligman, A. (1978). Communication of gender from human axillary odors: relationship to perceived intensity and pleasantness. *Behavioral Biology*, *23*, 373–380. http://doi.org/10.1016/S0091-6773(78)91393-7

Draelos, Z. (2001). Antiperspirants and the hyperidrosis patient. *Dermatologic Therapy*, *14*, 220–224. Retrieved from papers2://publication/uuid/62C55F7F-A210-4407-A175-9DF52784B986

Fialová, J., & Havlíček, J. (2012). Perception of emotion-related body odours in humans. *Anthropologie*, *50*(1), 95–110.

Fialová, J., Roberts, S. C., & Havlíček, J. (2016). Consumption of garlic positively affects hedonic perception of axillary body odour. *Appetite*, *97*, 8–15. http://doi.org/10.1016/j.appet.2015.11.001

Gallagher, M., Wysocki, C. J., Leyden, J. J., Spielman, A. I., Sun, X., & Preti, G. (2008). Analyses of volatile organic compounds from human skin. *Br J Dermatol*, *159*(4), 780–791. http://doi.org/10.1111/j.1365-2133.2008.08748.x.Analyses

Gunaydin, G., Selcuk, E., & Zayas, V. (2016). Impressions based on a portrait predict, one-month later, impressions following a live interaction. *Social Psychological and Personality Science*. http://doi.org/10.1177/1948550616662123

Havlicek, J., & Lenochova, P. (2006). The effect of meat consumption on body odor attractiveness. *Chemical Senses*, *31*(8), 747–752. http://doi.org/10.1093/chemse/bjl017

Havlíček, J., Lenochová, P., Oberzaucher, E., Grammer, K., & Roberts, S. C. (2011). Does Length of Sampling Affect Quality of Body Odor Samples? *Chemosensory Perception*, *4*, 186–194. http://doi.org/10.1007/s12078-011-9104-6

Havlicek, J., Saxton, T. K., Roberts, S. C., Jozifkova, E., Lhota, S., Valentova, J., & Flegr, J. (2008). He sees, she smells? Male and female reports of sensory reliance in mate choice and non-mate choice contexts. *Personality and Individual Differences*, *45*(6), 565–570. http://doi.org/10.1016/j.paid.2008.06.019

Hayes, A. F. (2006). A primer on multilevel modeling. *Human Communication Research*, *32*(4), 385–410. http://doi.org/10.1111/j.1468-2958.2006.00281.x

Herz, R. S., & Inzlicht, M. (2002). Sex differences in response to physical and social factors involved in human mate selection. The importance of smell for women. *Evolution and Human Behavior*, *23*(5), 359–364. http://doi.org/10.1016/S1090-5138(02)00095-8

Jacob, S., McClintock, M. K., Zelano, B., & Ober, C. (2002). Paternally inherited HLA alleles are associated with women's choice of male odor. *Nature Genetics*, *30*(2), 175–179. http://doi.org/10.1038/ng830

Keller, A., Zhuang, H., Chi, Q., Vosshall, L. B., & Matsunami, H. (2007). Genetic variation in a human odorant receptor alters odour perception. *Nature*, *449*(7161), 468–472. http://doi.org/10.1038/nature06162

Kippenberger, S., Havlíček, J., Bernd, A., Thaçi, D., Kaufmann, R., & Meissner, M. (2012). "Nosing Around" the human skin: What information is concealed in skin odour? *Experimental Dermatology*, *21*(9), 655–659. http://doi.org/10.1111/j.1600-0625.2012.01545.x

Kirk-Smith, M. D., & Booth, D. A. (1987). Chemoreception in human behaviour: experimental analysis\rof the social effects of fragrances. *Chemical Senses*, *12*(1), 159–166.

Lenochová, P., Vohnoutová, P., Roberts, S. C., Oberzaucher, E., Grammer, K., & Havlíček, J. (2012). Psychology of fragrance use: Perception of individual odor and perfume blends reveals a mechanism for idiosyncratic effects on fragrance choice. *PLoS ONE, 7*(3), 1–10. http://doi.org/10.1371/journal.pone.0033810

Lübke, K. T., Hoenen, M., & Pause, B. M. (2012). Differential processing of social chemosignals obtained from potential partners in regards to gender and sexual orientation. *Behavioural Brain Research*, *228*(2), 375–387. http://doi.org/10.1016/j.bbr.2011.12.018

Martins, Y., Preti, G., Crabtree, C. R., Runyan, T., Vainius, A. A., & Wysocki, C. J. (2005). Preference for human body odors is influenced by gender and sexual orientation. *Psychological Science*, *16*(9), 694–701. http://doi.org/10.1111/j.1467-9280.2005.01598.x

Mennella, J. A., Jagnow, C., & Beauchamp, G. K. (2001). Prenatal and postnatal flavor learning by human infants. *Pediatrics, 107*(6), E88. http://doi.org/10.1016/j.pestbp.2011.02.012.Investigations

Milinski, M., & Wedekind, C. (2001). Evidence for MHC-correlated perfume preferences in humans. *Behavioral Ecology*, *12*(2), 140–149. http://doi.org/10.1093/beheco/12.2.140

Minami, T., Boku, T., Inada, K., Morita, M., & Okazaki, Y. (1989). Odor components of human breath after the ingestion of grated raw garlic. *Journal of Food Science*, *54*(3), 3–4.

Olsson, M. J., Lundström, J. N., Kimball, B. a, Gordon, A. R., Karshikoff, B., Hosseini, N., … Lekander, M. (2014). The scent of disease: human body odor contains an early chemosensory cue of sickness. *Psychological Science*, *25*(3), 817–23. http://doi.org/10.1177/0956797613515681

Pause, B. M. (2012). Processing of Body Odor Signals by the Human Brain. *Chemosensory Perception*, *5*(1), 55–63. http://doi.org/10.1007/s12078-011-9108-2

Penn, D. J., Oberzaucher, E., Grammer, K., Fischer, G., Soini, H. A., Wiesler, D., … Brereton, R. G. (2007). Individual and gender fingerprints in human body odour. *Journal of the Royal Society, Interface*, *4*(13), 331–340. http://doi.org/10.1098/rsif.2006.0182

Prehn-Kristensen, A., Wiesner, C., Bergmann, T. O., Wolff, S., Jansen, O., Mehdorn, H. M., … Pause, B. M. (2009). Induction of empathy by the smell of anxiety. *PloS One*, *4*(6), e5987. http://doi.org/10.1371/journal.pone.0005987

Prokop-Prigge, K. A., Mansfield, C. J., Parker, M. R., Thaler, E., Grice, E. A., Wysocki, C. J., & Preti, G. (2014). Ethnic/Racial and Genetic Influences on Cerumen Odorant Profiles. *Journal of Chemical Ecology*, *41*(1), 67–74. http://doi.org/10.1007/s10886-014-0533-y

Semin, G. R. (2015). Mysterious communication : The secret language of chemosignals . In M. Van Brakel, W. Eikelboom, & F. Duernick (Eds.), *Sense of Smell* (pp. 156–161). Netherlands: The Eriskay Connection.

Shelley, W. B., Hurley, H. J., & Nichols, A. C. (1953). Axillary odor: Experimental study of the role of bacteria, aporcine sweat, and deodorants. *Ama Archives of Dermatology and Syphilology*, *68*(4), 430–446.

Sorokowska, A., Sorokowski, P., & Havlíček, J. (2016). Body Odor Based Personality Judgments: The Effect of Fragranced Cosmetics. *Frontiers in Psychology*, *7*(April). http://doi.org/10.3389/fpsyg.2016.00530

Zhou, W., & Chen, D. (2009). Fear-related chemosignals modulate recognition of fear in ambiguous facial expressions. *Psychological Science*, *20*(2), 177–183. http://doi.org/10.1111/j.1467-9280.2009.02263.x

Supplemental Materials

Study 1

Materials and methods

Participants. Forty self-reported heterosexual female non-smokers ages 18-27 years old from Cornell University were recruited via flyers posted around campus and emailed to students interested in participating in psychological research. We recruited raters and donors with different flyers, each listing the study under a separate name so that participants would not realize the true aim of the study. Participants were allowed to select money ($35), extra credit in their Psychology classes, or a combination of the two in exchange for their participation. Twenty-two participants were donors and eighteen participants were raters. We allowed a maximum of 10 raters and 10 donors to sign up for each session, but low enrollment and attrition contributed to lower numbers.

Intake materials. When they arrived at the lab to participate in the live rating session, each participant filled out an intake form with questions about menstrual cycle, birth control use, current health status, upcoming stressful events, and daily use of hygiene products, including but not limited to perfume, deodorant, and shampoo. Because our sample consisted of a mix of birth control users and non-users, we did not investigate the influence of raters' or donors' menstrual cycle on social judgments. We hoped to assess whether using the same products would cause raters to judge donors more favorably than those who used different products. However, few of our donors were able to accurately report both the brand and the scent of the products we used. Among those who did report specific products, there were very few matches, so we were not able to use this information. We also asked participants to answer questions related to their odor sensitivity, but as we did not use a validated measure we did not feel confident in using this data to predict results.

Data analytic strategy. Because judgments of individual donors were nested within raters, we used multilevel models (MLMs) with a restricted maximum likelihood estimation (Hayes, 2006) to account for interdependency among data points.

Estimating Statistical Power. Statistical power was estimated using the procedures outlined by Snijders and Bosker to estimate power in two-level mixed models using the software PINT v. 2.1 (Snijders and Bosker 1993). For the purpose of estimating power, we assumed residual perceiver-level variance of 57%, and random intercept variance of 8%. Further, because the number of donors varied across raters (see Table S1), our power analysis is based on each rater (n = 18) judging 8 donors, which best approximates the total number of actual measurements (144 (estimate) vs. 138 (actual)). The standard error for the association between round 1 and round 2 judgments was estimated as 0.06. Based on this estimate, at α=0.05 (two-tailed), the power to detect a standardized association of 0.3 between round 1 and round 2 judgments was > 99%.

Table S1
Study 1: Number of raters and donors for each group.

Group	*n* raters	*n* donors	Total observations per round
Group 1	5	4	20
Group 2	7	10	70
Group 3	6	8	48

Testing for Fixed vs. Random Intercepts. For all dependent variables, we tested whether the intercept varied randomly across raters and donors using a Log Likelihood test (Hayes, 2006). The intercept was allowed to vary randomly if the test result was statistically significant (i.e., $\chi^2 > 3.84$). There was no appreciable effect of allowing intercepts to vary randomly as a function of donor on any of the variables (all χ^2s < 2.42). However, as shown in Table S2, the intercept varied significantly as a function of rater on 6 of the 10 variables, including half of the variables in our liking aggregate. For all the models, we therefore treated the intercept as a random effect at the level of the rater, but not at the level of donor.

Table S2

Study 1: Does allowing the intercept to vary randomly as a function of rater and donor improve the model? Results of Hayes' likelihood ratio test for determining whether to treat the intercept as fixed or random at the level of rater or donor.

Judgment	Model 1	Model 2	*Diff.*	χ^2	Model 3	*Diff.*	χ^2
	-2 log likelihood	-2 log likelihood		*p* value	-2 log likelihood		*p* value
Liking (aggregate)	334.77	329.86	4.91	.027	334.68	.09	.764
Pleasant Odor +	353.56	342.91	10.65	.001	353.27	.29	.590
Friendly +	359.84	356.63	3.21	.073	359.73	.11	.740
Have a convo? +	323.26	320.02	3.24	.072	323.26	0	>.999
Pleasant to sit by +	349.39	341.31	8.08	.004	349.39	0	>.999
Intense Odor	339.78	332.87	6.91	.009	339.52	.26	.610
Familiar	384.27	375.06	9.21	.002	381.86	2.41	.121
Similar to own smell	353.45	344.46	8.99	.003	353.45	0	>.999
Similar to female best friend.	344.63	321.16	23.47	<.001	344.63	0	>.999
Similar to male best friend	329.93	321.40	8.53	.003	329.93	0	>.999

Notes. Hayes' likelihood ratio test (Hayes, 2006) allows comparison between two models where the component of interest is fixed in one model and random in the other. The method calls for comparing the -2 log likelihoods of these models and examining their difference with a chi-square test. *df* is determined by the number of parameters by which the models differ, which in our case is always 1. Statistically significant values indicate a rejection of the null hypothesis that the variance of the random component is zero. In all models reported here, the slopes are treated as fixed predictors at the level of rater and donor. *Model 1*: The intercept is treated as fixed at the level of rater and donor. *Model 2*: The intercept is treated as random at the level of rater and fixed at the level of donor is fixed. *Model 3*: The intercept is treated as fixed at the level of rater and random at the level of donor.

We used the same approach to test whether the slopes, representing the consistency in judgments across rounds, varied significantly across raters, and across donors. As shown in Table S3, when we allowed the slope to vary randomly at the level of rater, only one test was statistically significant (similarity to female friend: $\chi^2 = 7.62$, $p = .006$). When we allowed slope to vary randomly at the level of donor, only two of our ten tests were statistically significant (pleasant: $\chi^2 = 16.69$, $p < .001$; similarity to male friend: $\chi^2 = 7.14$, $p = .008$). Because only three of the 20 tests indicated statistically significant variability in the slope, we treated slope as fixed at the level of both rater and donor. Even when the results suggest that adding slope as a random factor significantly improves the fit of the model, the conclusions drawn do not change appreciably.

Table S3

Study 1: Does allowing rater and donor slopes to vary randomly improve the model? Results of Hayes' likelihood ratio test for determining whether to treat the slope as fixed or random at the level of rater or donor.

Judgment	Model 1	Model 2	*Diff.*	χ^2	Model 3	*Diff.*	χ^2
	-2 log likelihood	-2 log likelihood		*p* value	-2 log likelihood		*p* value
Liking (aggregate)	329.86	329.83	.03	.862	324.51	5.35	.021
Pleasant Odor +	342.91	342.89	.02	.888	326.22	16.69	<.001
Friendly +	356.63	356.63	.00	>.999	353.20	3.43	.064
Have a convo? +	320.02	316.62	3.40	.065	318.82	1.20	.273
Pleasant to sit by +	341.31	340.90	.41	.522	337.37	3.49	.062
Intense Odor	332.87	332.87	.00	>.999	332.48	.39	.532
Familiar	375.06	375.06	.00	>.999	374.94	.12	.729
Similar to own smell	344.46	343.70	.76	.383	344.40	.06	.806
Similar to female best friend.	321.16	313.55	7.61	.006	318.80	2.36	.124
Similar to male best friend	321.40	317.22	4.18	.041	314.26	7.14	.008

Notes. Hayes' likelihood ratio test (Hayes, 2006) allows comparison between two models where the component of interest is fixed in one model and random in the other. The method calls for comparing the -2 log likelihoods of these models and examining their difference with a chi-square test. *df* is determined by the number of parameters by which the models differ, which in our case is always 1. Statistically significant values indicate a rejection of the null hypothesis that the variance of the random component is zero. In all models reported here, the intercept is treated as random at the level of rater and fixed at the level of donor. *Model 1*: The slope is treated as fixed at the level of rater and donor. *Model 2*: The slope is treated as random at the level of rater and fixed at the level of donor. *Model 3*: The slope is treated as fixed at the level of rater and random at the level of donor.

Results

Auxiliary analyses: Testing for donor effects. To what extent is consistency in live, whole body olfactory-based judgments driven by the odors of particular donors (i.e., a donor effect)? We conducted auxiliary analyses to provide a stringent control for possible donor effects. We reasoned that to the extent that consistency in olfactory-based judgments is the result of donor effects, then round 1 judgments for any given rater should predict round 2 judgments for a *different*, randomly selected rater. To test whether this was the case, we first randomly paired raters, and then ran a series of

MLMs to assess the predictive ability of each rater's own round 1 judgments (*matched data*), compared to another randomly paired rater's round 1 judgment (*mismatched data*), in predicting round 2 judgments. We describe the steps of these analyses below.

Creating randomly paired data. To create our mismatched data set, we used an online list randomizer (www.random.org/lists) to create randomly paired raters. To ensure an equal number of observations for each rater, we randomized within each group.

Data analytic strategy. We conducted three analyses to investigate the extent to which olfactory-based judgments were driven by donor effects.

In our first set of analyses, we simply examined the extent to which raters' round 2 judgments were predicted by round 1 judgments from a different (randomly paired) rater. For comparison purposes, we also report here again the results from a model (*Model 1a*) with raters' *own* round 1 judgments (which we refer to simply as *matched*) as the predictor of the same raters' round 2 judgments. In contrast, in *Model 1b*, the round 1 judgment for the randomly paired rater (*mismatched*) was the predictor, and the rater's own original round 2 judgment was the dependent variable.

Second, we examined the extent to which round 1 own judgment predicted round 2 judgments, after statistically controlling for any predictive ability of mismatched data. In Model 2, both matched and mismatched round 1 judgments were simultaneously entered into the model predicting round 2 judgments.

Finally, we examined the extent to which rater's own matched data showed statistically greater predictive ability than mismatched data. In other words, are the level-1 coefficients, reflecting consistency in olfactory-based judgments, greater (more positive) for matched than mismatched data? To do so, we created a data file in which we "stacked" the matched and mismatched round 1 data, created a new variable (which we refer to simply as *matchcode*) to denote matched or mismatched status, and then paired both sets with the round 2 data. In this model (Model 3), round 2 judgments were the dependent variable, and round 1 judgments, matchcode, and the round 1 judgment × matchcode interaction were entered as level 1 predictors.

Results. If there are no appreciable effects of donors, then the mismatched data should be random and should not necessarily predict round 2 judgments. However, as shown in Table S4, mismatched data predicted round 2 judgments for liking, as reflected by the aggregate liking measure ($\beta = .22$, $p = .008$), willingness to sit by ($\beta = .23$, $p = .004$), and intensity ($\beta = .42$, $p < .001$). These results suggest that some donors were consensually evaluated more favorably, and more intensely, than other donors.

Table S4

Study 1: Assessing the role of donor effects on consistency of olfactory judgments. Level-1 coefficients representing the predictive ability of a rater's own round 1 judgments (matched data) and a randomly paired rater's round 1 judgments (mismatched data) on round 2 judgments.

Question		Models 1a and 1b			Model 2	
	β	SE	*p*	β	SE	*p*
Liking (aggregate)						
Matched	.55	.07	<.001	.52	.07	<.001
Mismatched	.22	.08	.007	.08	.07	.250
Pleasant Odor+						
Matched	.50	.07	<.001	.49	.07	<.001
Mismatched	.15	.08	.070	.09	.07	.202
Friendly+						
Matched	.42	.08	<.001	.41	.08	<.001
Mismatched	.17	.08	.045	.02	.08	.766
Have a conversation?+						
Matched	.57	.07	<.001	.55	.07	<.001
Mismatched	.19	.09	.030	.08	.07	.289
Pleasant to sit by+						
Matched	.47	.07	<.001	.43	.07	<.001
Mismatched	.22	.08	.005	.12	.07	.101
Intense Odor						
Matched	.55	.07	<.001	.46	.06	<.001
Mismatched	.42	.07	<.001	30	.06	<.001
Familiar						
Matched	.07	.09	.467	.06	.09	.493
Mismatched	.07	.09	.450	.07	.09	.460
Similar to own smell						
Matched	.42	.08	<.001	.42	.08	<.001
Mismatched	.04	.08	.670	.03	.08	.746
Similar to female best friend						
Matched	.39	.07	<.001	.39	.07	<.001
Mismatched	.07	.07	.338	.04	.07	.558
Similar to male best friend						
Matched	.47	.07	<.001	.46	.07	<.001
Mismatched	.07	.08	.400	.02	.07	.762

Notes. In all models, the dependent variable is round 2 judgments. In model 1a, the predictor is rater's own round 1 data (matched). In model 1b, the predictor is a randomly paired rater's round 1 data (mismatched). In Model 2, round 1 matched and mismatched judgments are entered simultaneously as level-1 predictors. Values based on standardized scores (z scores).

Critically, for all judgments for which we had observed consistency as a function of olfactory-based cues, raters' *own* round 1 judgments (matched data) were stronger predictors of round 2 judgments, than a different rater's round 1 judgments (mismatched data; see Table S4). For example, with regard to the liking aggregate, the level-1 slope coefficient for raters' own round 1 judgments predicting the same raters' round 2 judgments was .55, $p < .001$. In contrast, for the mismatched data, in which a randomly paired rater's round 1 judgments predicted another rater's round 2 judgments, the level-1 slope coefficient was .22, $p = .008$. Indeed, the matched round 1 data was a significantly stronger predictor than the mismatched round 1 data, as reflected by a statistically significant matchcode × round 1 judgment interaction, for all judgments, except for intensity ($\beta = -.22$, $p = .03$) and familiarity ($\beta = -.28$, $p = .014$) (see Table S5).

Table S5

Study 1: Assessing whether a rater's own round 1 judgments predict round 2 judgments better than mismatched judgments using matchcode*, a categorical variable denoting the matched/mismatched status of each data pair.*

Question	Round 1 judgment		Matchcode × round 1 judgment	
	β	*p*	β	*p*
Liking (aggregate)	.58	<.001	.41	<.001
Pleasant Odor+	.51	<.001	.37	<.001
Friendly+	.45	<.001	.34	.002
Have a conversation?+	.60	<.001	.51	<.001
Pleasant to sit by+	.50	<.001	.32	.002
Intense Odor	.59	<.001	.22	.03
Familiar	.22	.014	.28	.014
Similar to own smell	.42	<.001	.33	.002
Similar to female best friend	.39	<.001	.36	<.001
Similar to male best friend	.46	<.001	.43	<.001

Notes. Matchcode indicates whether round 1 judgments were from the same rater (matchcode = 1) or from different raters (matchcode = 0). Because the data were standardized before creating the random pairs, matched and mismatched data had identical means and SDs. Thus, for all judgments, there is no effect of matchcode (β and *p* values for *matchcode* were 0 and 1, respectively). A statistically significant matchcode × round 1 judgment interaction term signifies a difference in the predictive ability between own (matched) and mismatched data on round 2 judgments.

Finally, we aimed to assess the extent to which raters' own round 1 judgments (matched) predicted round 2 judgments above any effect of mismatch data. As shown in Table S4 (under Model 2), raters' own data continued to uniquely predict round 2 judgments, above and beyond the mismatched data, for all variables (except familiarity which did not reveal consistency). Additionally, when both matched and mismatched data were included in the model, the slope estimates for the mismatched data were no longer statistically significant, except for intensity.

In sum, the results of these auxiliary analyses indicate the presence of donor effects. That is, based on olfactory cues some donors are evaluated more favorably than others, and this contributes to consistency for the majority of our raters. But, importantly, donor effects don't fully account for the observed within-person consistency; for all judgments, raters' own round 1 judgments were significantly stronger predictors of round 2 judgments, than the round 1 judgments of a randomly paired rater. Moreover, even after statistically controlling for the mismatched data, our overall conclusions regarding the consistency of olfactory-based social judgments remain unchanged: raters show stable consistency in their olfactory judgments above and beyond donor effects.

Study 2

Materials and methods

Participant recruitment. We advertised for raters and donors with separate study names on flyers and online postings, and allowed participants to choose their mode of compensation - $35 for raters and $50 for donors, or equivalent class credit. We again recruited the maximum possible number of participants for each session. A total of 3 raters and 2 donors failed to attend on the second Saturday, but we were able to recruit 2 raters in the afternoon session to keep our numbers similar. Because MLM allows the number of donors to vary for each particular rater, the loss of the 2 donors had minimal effect on our analyses. The 3 raters who participated in only a single session were included in all analyses, except necessarily when comparing natural and diplomatic ratings, which were assessed across both days.

Washout materials. Participants were provided with Hanes brand 100% cotton *t*-shirts in a child's extra-large size, ensuring a relatively tight fit for all participants. We provided them with JĀSÖN Fragrance Free Pure Natural Shampoo (also used as body wash), Whole Foods 365 Fragrance Free Conditioner, and Ēcos Free and Clear Unscented Laundry Detergent.

Washout instructions, odor collection, and self-report questionnaire. Participants were provided with fragrance-free soap, shampoo, conditioner, and laundry detergent and instructed to use the detergent to wash sheets, towels, and any clothing that would come in contact with their *t*-shirt on collection day and during the live session. Beginning in the morning 2 days before odor collection, participants were asked to shower with unscented products each morning and to refrain from wearing deodorant or scented hygiene products, smoking, drinking alcohol, and eating strongly odorous foods including garlic, curry, asparagus, and spicy foods. On the day of odor collection, participants were instructed to put on one clean *t*-shirt following their morning shower and to wear it for at least 12 hours during the day, while continuing the wash out restrictions and avoiding particularly smelly places like smoky bars. They were instructed to place the *t*-shirt in a ziplock bag in the freezer over night, and then to wear the same shirt to the lab the following day during the study. For the duration of the washout and collection period (a total of 3 days), participants were asked to fill out a self-report form about their activities during the day and their adherence to the wash-out rules, in order for us to monitor compliance and to encourage participants to think actively about their participation in the study. For diplomatic odor collection, we simply asked participants to put a shirt on in the morning and wear it for at least 12 hours, then place it in the freezer over night and wear it to the lab the next day. In the morning group, donors completed the washout and natural odor collection before the first live session, and collected diplomatic odor the day before the second session. The afternoon group completed these tasks in the opposite order.

Data analytic strategy.

Estimating Statistical Power. As in Study 1, we followed procedures outlined by Snijders and Bosker to estimate power in two-level mixed models (Snijders & Bosker, 1993). For all tests of key hypotheses, we assumed residual perceiver-level variance of 57% and random intercept variance of 8%. Further, because the number of donors varied across raters, and these numbers varied depending on the particular hypothesis being tested (see Table S6), we adjusted our power analysis based on the particular number of observations available (i.e., raters and donors available) for a given hypothesis. For our key hypotheses, the standard error for the association between round 1 and round 2 judgments was estimated as 0.07. Based on this estimate, at α=0.05 (two-tailed), the power to detect a standardized association of 0.3 between round 1 and round 2 judgments was > 99%.

Table S6
.Study 2: Number of raters and donors for each group as a function of odor type (diplomatic and natural).

	Diplomatic			*Natural*		
Group	*n* raters	*n* donors	Total observations per round	*n* raters	*n* donors	Total observations per round
Group 1	9	9	81	10	10	100
Group 2	5	9	45	6	7	42

Moderators and covariates**.** Participants were run in two separate groups, morning and afternoon, each across 2 different weeks. Odor condition (diplomatic vs. natural) varied by week, with the morning group smelling natural odor on the first week and diplomatic odor on the second week, and the afternoon group smelling these odor types in the reverse order. 3 raters and 2 donors failed to attend on the second week; 2 of the donors were replaced with new participants. The replacement raters and their counterparts who participated the first week were included in analyses regarding the relationship between round 1 and round 2 judgments for the day they participated, as well as that day's comparison between live and t-shirt ratings, but excluded from analyses regarding the relationship between natural and diplomatic odor, as each of these participants judged only a single odor condition. We tested whether our results differed by both group (morning or afternoon) and condition (natural or diplomatic). We ran a model in which round 2 judgments were the dependent variable, and round 1 judgments, group, and odor type were the predictors, along with all two- and three-way interactions. We allowed the intercept to vary randomly at the level of raters and donors, but kept the slopes fixed for both.

The results of these analyses are shown in Table S7. There were no statistically significant interactions between group and round 1 judgments for all variables, except for familiarity, which showed a statistically significant three way interaction (Odor type × Group × Round1) and intensity and similarity to self, which showed a statistically significant two-way interaction (Group × Round1). When we investigated these interactions more closely, in all three cases, olfactory-based consistency was observed in both AM and PM groups, but was stronger in one group than the other. Given that we did not have *a priori* expectations for group differences, and these interactions do not appreciably change our conclusions regarding consistency in olfactory-based judgments, we do not discuss them further.

We likewise tested whether the effect of group moderated the relationship between live and *t*-shirt based judgments (see Table S8). We ran a similar model testing the effects of group and presentation type (live or on *t*-shirts) for natural ratings predicting diplomatic ratings (see Table S9).

Table S7

Study 2: Does group (morning or afternoon) and odor type (natural or diplomatic) moderate the effect of round 1 judgments predicting round 2 judgments (collapsing across live and t*-shirt methods)? p values for predictors and interactions.*

Predictor	Liking (aggregate)	Pleasant odor	Friendly	Have a conversation?	Pleasant to sit by	Intense odor	Familiar	Similar to own smell	Similar to female best friend	Similar to male best friend
Intercept	.857	.677	.938	.708	.635	.470	.664	.764	.908	.774
Round 1	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	.052	**<.001**	**<.001**	**<.001**
Odor type	.862	.712	.997	.172	.468	.347	.017	.261	.217	.897
Group	.235	.235	.229	.089	.200	.216	.057	.642	.889	.336
Odor type × Group	.661	.456	.818	.887	.755	.576	**.002**	.352	.322	.592
Odor type × Round1	.028	.018	.239	.052	.090	.901	.010	.979	.329	.774
Group × Round 1	.239	.213	.910	.558	.038	**.002**	.944	**.001**	.400	.956
Odor type × Group × Round1	.068	.273	.096	.009	.015	.013	**.001**	.468	.342	.766

Notes. All values based on standardized scores (z scores). *p* values that are significant with our experiment-wise correction for multiple comparisons are in bold (*p* value cutoff is .05/6, or .0083). Values reflect the combined data for live and *t*-shirt ratings.

Table S8

Does group (morning or afternoon) and odor type (natural or diplomatic) moderate the effect of live judgments predicting t*-shirt based judgments? p values for predictors and interactions.*

Predictor	Liking (aggregate)	Pleasant odor	Friendly	Have a conversation?	Pleasant to sit by	Intense odor	Familiar	Similar to own smell	Similar to female best friend	Similar to male best friend
Live judgments	.020	.290	**.001**	**<.001**	.016	**.001**	**<.001**	**.004**	**<.001**	**<.001**
Odor type	.014	.501	.761	.759	.832	.395	.408	.508	.286	.916
Group	.751	.511	.940	.831	.984	.792	.174	.458	.821	.903
Odor type × Group	.107	.058	.275	.358	.615	.002	064	.263	.115	.859
Odor type × Live judgments	.166	.236	.918	.126	.050	.998	.169	.615	.233	.167
Group × Live judgments	.038	.027	.641	.034	.029	.869	.165	.799	.849	.025
Odor type × Group × Live judgments	.284	.271	.729	.441	.397	.998	.306	.943	.111	.211

Notes. All values based on standardized scores (z scores). Live judgments are based on the mean of round 1 and round 2 ratings. *p* values that are significant with our experiment-wise correction for multiple comparisons are in bold (*p* value cutoff is .05/6, or .0083).

Table S9

Study 2: Does group (morning or afternoon) and presentation method (live or on t-shirts) moderate the effect of judgments based on natural odor predicting judgments based on diplomatic odor? p values for predictors and interactions.

Predictor	Liking (aggregate)	Pleasant odor	Friendly	Have a conversation?	Pleasant to sit by	Intense odor	Familiar	Similar to own smell	Similar to female best friend	Similar to male best friend
Natural (judgments)	.874	.752	.979	.010	.905	**<.001**	.033	.014	.024	.473
Method	.027	.030	.429	.025	.125	.438	.113	.803	.760	.271
Group	.251	.487	.212	.064	.157	.054	.152	.683	.815	.574
Method × Group	**<.001**	**.001**	.051	**<.001**	**.001**	.432	.020	.685	.843	.434
Method × Natural	.901	.994	.992	.999	.278	.643	.106	.961	.581	.471
Group × Natural	**.002**	**<.001**	**.003**	.270	.025	.145	.891	.974	.461	.997
Method × Group × Natural	**.004**	**.001**	.018	**.008**	.012	.932	.988	.210	.175	.037

Notes. All values based on standardized scores (z scores). Values for live judgments are based on the mean of round 1 and round 2 ratings within each odor condition. *p* values that are significant with our experiment-wise correction for multiple comparisons are in bold (*p* value cutoff is .05/6, or .0083)

Testing for Fixed vs. Random Intercepts. As in study 1, we used a log ratio test to determine whether to allow intercepts and slopes to vary randomly with regard to raters and donors. We chose to allow the intercept to vary randomly for both rater and donor (See Tables S10 for details), but to keep the slopes for both rater and donor fixed.

Table S10

Study 2: Does allowing rater and donor intercepts to vary randomly improve the model?

Judgment	Model 1	Model 2	*Diff.*	χ^2	Model 3	*Diff.*	χ^2
	-2 log likelihood	-2 log likelihood		*p* value	-2 log likelihood		*p* value
Liking (aggregate)	632.91	632.16	.75	.386	612.44	20.47	<.001
Pleasant Odor +	647.92	647.43	.49	.484	628.61	19.31	<.001
Friendly +	664.47	663.21	.26	.610	650.64	13.83	<.001
Have a conversation? +	631.97	622.18	9.80	.002	618.83	13.14	<.001
Pleasant to sit by +	644.35	643.65	.70	.403	626.43	17.91	<.001
Intense Odor	643.34	641.64	1.69	.194	624.52	18.82	<.001
Familiar	704.82	675.91	28.91	<.001	692.73	12.09	<.001
Similar to own smell	680.70	651.74	28.96	<.001	680.67	.03	.862
Similar to female best friend	654.04	637.31	16.73	<.001	654.04	.00	>.999
Similar to male best friend	663.61	645.61	17.99	<.001	663.60	.01	.920

Notes. Hayes' likelihood ratio test (Hayes, 2006) allows comparison between two models where the component of interest is fixed in one model and random in the other. The method calls for comparing the -2 log likelihoods of these models and examining their difference with a chi-square test. *df* is determined by the number of parameters by which the models differ, which in our case is always 1. Statistically significant values indicate a rejection of the null hypothesis that the variance of the random component is zero. In all models reported here, the slopes are treated as fixed predictors at the level of rater and donor. *Model 1*: the intercept is treated as fixed at the level of rater and donor. *Model 2*: the intercept is treated as random at the level of rater and fixed at the level of donor. *Model 3*: the intercept is treated as fixed at the level of rater and random at the level of donor.

Results

Testing for donor effects using a mismatched data set. We followed the procedures used in Study 1 (described on p.5-7) to provide a more stringent control of potential donor effects. We again randomly paired raters within each group and in Study 2 also within each session (natural vs. diplomatic) to control for the fact that we had two replacement raters on day 2. The results of the three auxiliary analyses are reported in Tables S11 and S12.

Similar to study 1, there was evidence of donor effects. The mismatched data predicted round 2 judgments for the aggregate liking measure, the individual liking items, and intensity (see Table S11). These results suggest that some donors were consistently evaluated more favorably and more intensely than other donors. Critically, for all judgments, raters' *own* round 1 judgments (matched) were stronger predictors of round 2 judgments, than a different rater's round 1 judgments (mismatched). The greater predictive ability for raters' own round 1 judgments (vs. mismatched data), which was reflected by statistically significant matchcode × round 1 judgment interactions, was evident for all judgments except intensity ($\beta = -.199$, $p = .011$) and pleasantness to sit by ($\beta = -.192$, $p = .014$) (see Table S12). Moreover, when we statistically controlled for the effect of mismatch data, raters' own data continued to predict round 2 judgments for all variables (see Table S11).

In sum, the results of these auxiliary analyses reveal the presence of donor effects. But, even after statistically controlling for donor effects (estimated via the predictive ability of mismatched data), raters demonstrate substantial consistency in their judgments based on olfactory-cues.

Table S11

Study 2: Looking at possible donor effects by comparing the predictive value of matched and mismatched data sets.

Question	Models 1a and 1b			Model 2		
	B	SE	*p*	β	SE	*p*
Liking (aggregate)						
Matched	0.47	0.05	<.001	0.45	0.05	<.001
Mismatched	0.18	0.06	.002	0.10	0.05	.062
Pleasant Odor+						
Matched	0.45	0.05	<.001	0.49	0.05	.001
Mismatched	0.16	0.06	.005	0.18	0.05	.001
Friendly+						
Matched	0.43	0.05	<.001	0.46	0.06	.001
Mismatched	0.23	0.06	.000	0.09	0.06	.113
Have a conversation?+						
Matched	0.43	0.05	<.001	0.43	0.06	.001
Mismatched	0.17	0.06	.008	0.07	0.06	.199
Pleasant to sit by+						
Matched	0.41	0.05	<.001	0.47	0.05	.001
Mismatched	0.34	0.06	.000	0.22	0.05	.001
Intense Odor						
Matched	0.45	0.05	<.001	0.44	0.06	.001
Mismatched	0.38	0.06	.000	0.20	0.06	.001
Familiar						
Matched	0.37	0.06	<.001	0.17	0.06	.005
Mismatched	0.09	0.06	.137	0.07	0.06	.228
Similar to own smell						
Matched	0.13	0.06	.033	0.32	0.06	.001
Mismatched	-0.02	0.06	.768	-0.02	0.06	.677
Similar to female best friend						
Matched	0.32	0.05	<.001	0.41	0.06	.001
Mismatched	0.01	0.06	.877	0.02	0.05	.735
Similar to male best friend						
Matched	0.39	0.06	<.001	0.34	0.06	.001
Mismatched	-0.12	0.06	.052	-0.09	0.06	.101

Notes. In all models, the dependent variable is round 2 judgments. In model 1a, the predictor is rater's own round 1 data (matched). In model 1b, the predictor is a randomly paired rater's round 1 data (mismatched). In Model 2, round 1 matched and mismatched judgments are entered simultaneously as level-1 predictors. Values based on standardized scores (z scores).

Table S12

Study 2: Assessing whether a rater's own round 1 judgments predict round 2 judgments better than mismatched judgments using matchcode, *a categorical variable denoting the matched/mismatched status of each data pair*.

Question	Round 1 judgment		Matchcode × round 1 judgment	
	β	*p*	β	*p*
Liking (aggregate)	.42	<.001	.25	<.001
Pleasant Odor+	.40	<.001	.24	.001
Friendly+	.50	<.001	-.26	.001
Have a conversation?+	.49	<.001	-.41	<.001
Pleasant to sit by+	.53	<.001	-.19	.014
Intense Odor	.56	<.001	-.20	.011
Familiar	.27	<.001	-.27	.001
Similar to own smell	.40	<.001	-.54	<.001
Similar to female best friend	.50	<.001	-.59	<.001
Similar to male best friend	.41	<.001	-.63	<.001

Notes. Matchcode indicates whether round 1 judgments and round 2 judgments were from the same rater (matchcode = 1) or from different raters (matchcode = 0). Because the data were standardized before creating the random pairs, matched and mismatched data had identical means and SDs. Thus, for all judgments, there is no effect of matchcode (β and *p* values for *matchcode* were approximately 0 and 1, respectively). A statistically significant matchcode × round 1 judgment interaction term signifies a difference in the predictive ability between own (matched) and mismatched data on round 2 judgments.

References.

Hayes AF. (2006). A primer on multilevel modeling. Hum Commun Res. 32(4):385–410. http://doi.org/10.1111/j.1468-2958.2006.00281.x

Snijders TAB, Bosker RJ. (1993). Standard Errors and Sample Sizes for Two-Level Research. J Educ Behav Stat. 18(3):237-259. doi:10.3102/10769986018003237

CHAPTER 3

CAN LEARNED RESPONSES TO BODY ODOR AFFECT HUMAN SOCIAL INTERACTIONS? USING CLASSICAL AVERSIVE CONDITIONING TO EXPLORE THE EFFECTS OF BODY ODOR AND PERFUME

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Abstract

Body odor conveys a great deal of information about an individual, and is important in social evaluations and bonding. Most research on the topic of human body odor uses tightly controlled body odor samples that eliminate the use of exogenous fragrances, even though the use of perfume and other fragranced products is common across many cultures. Little is known about how these fragrances might interact with body odor to change social olfactory information. Given the communicative value of body odor and the increasing interest in the effects of perfume on that value, we investigated a) whether an aversive conditioning paradigm could induce learned responses to individual body odors; b) whether this effect might be enhanced by the addition of perfume worn by the odor donor; and c) whether this conditioned response could affect the interpretation of visual social information. Participants underwent a classical conditioning paradigm using electric shock, with either perfumed or unperfumed body odors as stimuli. During acquisition phase, we monitored galvanic skin response (GSR). After conditioning, subjects participated in two rounds of an ostensibly unrelated task where they were asked to rate the emotions of a set of neutral faces in the presence of both conditioned and control odors. Participants exhibited increased GSR activity in response to the conditioned odor on trials where they did *not* receive a shock ($p=.042$) during the second half of the conditioning paradigm, suggesting that conditioning was successful. We found no differences in conditioning success between perfumed and unperfumed body odors, suggesting that perfume does not mask underlying individual differences conveyed in natural body odor. In the

presence of the conditioned odors, participants perceived faces as significantly more surprised ($p < .001$), suggesting that learned information about olfactory stimuli may modify social perception in other modalities. To our knowledge, this is the first study to employ body odor in a conditioning paradigm. The success of conditioned body odors in shifting visual perception of social signals suggests that having emotional experiences with another individual, which includes the presence of that individual's body odor, may affect future interactions with and assessments of that person.

1. Introduction

A number of studies have shown that natural body odor, devoid of outside fragrance influences, contains social information. Body odor conveys cues related to mate fitness (Jacob, McClintock, Zelano, & Ober, 2002; Thornhill, 1999), genetic relatedness (Lundström, Boyle, Zatorre, & Jones-Gotman, 2009; Porter, Balogh, Cernoch, & Franchi, 1986), age (Mitro, Gordon, Olsson, & Lundström, 2012), gender and sexual orientation (Lübke, Hoenen, & Pause, 2012; Martins et al., 2005), and health (M. J. Olsson et al., 2014), among others. Additionally, body odor can convey emotional states (Cantafio, 2003; Chen & Haviland-Jones, 2000; Zhou & Chen, 2011), and sweat from individuals in highly emotionally charged states can actually modify physiological activity in those smelling these odors (de Groot et al., 2015; de Groot, Smeets, Kaldewaij, Duijndam, & Semin, 2012; Prehn-Kristensen et al., 2009). Importantly, each individual has a unique odor signature, which is heavily influenced by genetic factors (Natsch, Kuhn, & Tiercy, 2010; Pause et al., 2006). This odor signature is chemically identifiable and remains relatively consistent over time (Penn et al., 2007), but can be influenced by a number of environmental factors such as diet (Zuniga, Stevenson, Mahmut, & Stephen, 2016), disease (Buljubasic & Buchbauer, 2014; Olsson et al., 2014), and reproductive status, particularly for women (Havlíček, Dvořáková, Bartoš, & Flegr, 2006).

Investigation into the neural processing of odor indicates that we perceive body odor differently than other, non-human odors (Lundström, Boyle, Zatorre, & Jones-Gotman, 2008). In particular, body odors are processed by networks associated with the processing of emotional stimuli rather than those associated with processing olfactory stimuli (reviewed in Pause, 2012). The tight neural connections between the piriform cortex – one of the primary areas involved in processing non-human odors – and the hippocampus allow a visceral link between odor and memory, such that smelling a familiar odor can trigger vivid, long-forgotten memories, and experiences with odors can lead to the formation of long lasting odor-memory associations (Herz, 2011; Willander & Larsson, 2007). Anecdotally, the perfume of, for example, one's mother or an ex-boyfriend can evoke strong emotional memories associated with that person. The confluence of social and non-social processing of a multilayered signal – body odor combined with fragrance – may be responsible for this intimate association, though there is little research focused on investigating this topic.

Modification of body odor is common throughout many cultures, with the earliest perfumery dating back more than 4000 years (Roach, 2007). Perfume preferences are highly idiosyncratic and seem to be dictated in part by genetic factors (Hämmerli, Schweisgut, & Kaegi, 2012; Milinski & Wedekind, 2001) and in part by cultural and experiential factors (Havlíček & Roberts, 2013; Herz, 2011). Human sweat is actually odorless; it is the degradation of elements of this sweat by cutaneous microorganisms that produces body odor (Austin & Ellis, 2003; Troccaz et al., 2015). The interaction between fragrance and body odor can create a unique odor profile for each individual wearing a particular perfume (Allen, Havlíček, & Roberts, 2015). Typically, perceivers judge perfumed body odor to be more pleasant and attractive than non-perfumed (Allen et al., 2015; Lenochová et al., 2012). However, little research has investigated whether the application of perfume modifies the social signals contained in body odor, in addition to changing its hedonic value. The existing research indicates that perfume modifies perceptions of masculinity and femininity (Allen, Cobey, Havlíček, & Roberts, 2016) and competence (Baron, 1986), and may facilitate social interactions by encouraging prosocial behavior (Guéguen, 2001). Additionally, research suggests that wearing perfume may affect social interactions by changing the behavior of the perfume wearer, making them appear more confident to viewers (Higuchi, Shoji, Taguchi, & Hatayama, 2005; Roberts et al., 2009). However, currently no study has investigated the impact of fragrance on specific social signals, such as communication of emotion.

In the present study, we were interested in the effect of perfume on individual differences in body odor. Though some advances have been made regarding the effects of perfume on social interactions, it remains unclear whether perfume magnifies specific social signals contained in body odor, or whether it masks them. Milinski and Wedekind's (2001) finding that genotype is associated with perfume ingredient preferences suggests that we may choose perfumes that compliment our genotype, potentially magnifying cues contained in our body odor. Allen, Havlíček, and Roberts' (2015) finding that the use of perfumes dampens the ability to discriminate between individuals, however, suggests that perfumes may mask some of the cues contained in body odor. In order to investigate this question, we used a classical aversive learning paradigm to determine whether participants could learn to discriminate between two individual body odors. We reasoned that if perfume masks underlying signals of individual identity, then two individuals wearing the same fragrance would be perceived as the same individual. However, if perfume magnifies or has no effect on individual differences, then two individuals wearing the same fragrance would be easily discriminated.

Classical aversive conditioning has been shown to be an effective method for creating rapid emotional associations with specific odors (Åhs, Miller, Gordon, & Lundström, 2013; Li, Howard, Parrish, & Gottfried, 2008; Parma, Ferraro, Miller, Åhs, & Lundström, 2015). It has a robust effect with relatively few trials, and learned aversions have short extinction times (Gottfried and Dolan 2004). While classical conditioning has been used to create artificial emotional reactions to previously neutral odors (Åhs et al., 2013; Parma et al., 2015), the use of classical conditioning to create an emotional association with a body odor has yet to be investigated.

Previous research showing that humans can reliably identify the body odor of friends (Mallet & Schaal, 1998; S. B. Olsson, Barnard, & Turri, 2006) suggests that humans learn about others' body odors even though they may not feel that they are intentionally sampling olfactory information. In a real life relationship, this process would happen over time, with repeated exposures to an individual's body odor occurring during shared activities with that person. In our study, we aimed to use aversive conditioning to simulate this repeated exposure: participants repeatedly smelled two body odors, and one of those body odors was repeatedly paired with an aversive event (shock). This might mirror, for example, the experience of multiple encounters with someone who hurts your feelings each time you are together: over time, you might learn to associate that person and their body odor with a negative outcome, which would likely affect your behavior towards that person and your expectations for future encounters with them. By creating artificial experiential histories with body odors in our aversive conditioning paradigm, we hoped to gain some insight into this learning process and its potential involvement in social interactions (measured in our study by the perception of faces), as well as whether or not the process is affected by the presence of perfumes.

To address these issues, we first investigated the potential for classical aversive conditioning to create an artificial emotional valence for body odors, both combined with artificial fragrances and in isolation. Given that fragrances smell differently on different individuals (Behan, Macmaster, Perring, & Tuck, 1996), we hypothesized that participants would learn to discriminate between both plain body odors and fragranced body odors. Secondly, we investigated the potential for these conditioned odors to affect crossmodal interpretation of visual social cues. In paradigms using positively and negatively valenced non-human odors, presentation of an aversive odor can cause participants to interpret neutral faces more negatively than when smelling a neutral or appetitive scent (Li, Moallem, Paller and Gottfried 2007). We investigated whether a similar phenomenon would be observed for human body odors with negative or neutral valences (as determined by our conditioning paradigm). We expected that, following conditioning, the presence of a shock-paired odor would enhance the perception of negative emotions (fear, anger, sadness) in neutral faces, and diminish the perception of positive emotions (happiness).

2. Methods

2.1. Overview. Participants completed two tasks for this study: 1) an aversive conditioning paradigm designed to induce a negative association with either one of two *natural* body odors (devoid of outside fragrance influences) or one of two body odors paired with a fragrance; and 2) a face rating task where participants rated the emotions displayed in a set of neutral faces, once in the presence of a conditioned odor and once in the presence of a control odor. The conditioning paradigm was conducted between two sessions of a three-alternative forced choice task (3AFC) to determine whether participants were able to consciously discriminate between the two odors used in the paradigm (see 2.9), both before and after conditioning. During the acquisition phase of conditioning we measured galvanic skin response (GSR) in addition to asking participants self-report questions. The face rating task was presented as unrelated to the conditioning, under the auspices of being a pilot study, to prevent participants from suspecting its true purpose (examining the potential for learned odor associations to have crossmodal social effects).

2.2. Participants. We employed only female participants, as women tend to be more sensitive to odors than men, and because women tend to attribute more importance to olfactory information (Herz & Inzlicht, 2002). We excluded participants over the age of 40, as there are potential interaction effects between age and susceptibility to classical conditioning (LaBar et al. 2004). We also excluded bisexual and homosexual females, smokers, pregnant women, women with pacemakers or documented heart conditions, and women taking hormonal medications besides birth control. Participants were recruited via flyers posted in the community, word of mouth, online ads, and phone calls using a database of previous participant volunteers. In each case, participants were asked to complete a phone screening where the experimenter explained the nature of the study, including the fact that they would receive mild electrical shocks, to ascertain their interest in participating.

Experimenters also used this phone interview to ensure that participants did not violate any exclusion criteria.

Forty-eight self-reported heterosexual, nonsmoking females between the ages of 18 and 40 (mean age 27.5) participated in the study. All participants reported having normal olfactory function, and none reported any major head injuries. One participant asked to leave the study during the first three-alternative forced choice task, and experimenters were unable to record GSR for another. A total of 46 participants are included in the final analysis. A total of 10 participants reported taking hormonal birth control at the time of the study. On the day of testing, participants were asked to avoid wearing any perfumes or strongly scented lotions, and not to eat or drink anything except water for an hour before the study began.

2.3. Odor donors. Four self-reported heterosexual, nonsmoking Caucasian females ages 27-40 donated body odor. The odor donation process took a total of 8 days. The first two days were a "washout" period in order for donors to eliminate any outside odor sources that might affect body odor. We followed an established protocol (Chen & Haviland-Jones, 2000) that required participants to refrain from using any deodorants, antiperspirants, perfumes, or other fragranced products. Participants were also required to refrain from eating garlic, asparagus, spicy foods and curry, and to avoid drinking alcohol. We provided fragrance free soap, shampoo and conditioner and asked that participants shower with these products each day. We also provided fragrance free detergent and asked participants to wash sheets, towels, and clothing to be worn during the washout and odor donation period.

Once the washout period was complete, participants donated body odor over the following six days. Participants maintained all washout restrictions throughout the odor donation period, and were also asked to avoid sharing a bed, holding a pet, or engaging in heavy exercise or sexual activity while wearing their shirts. We provided participants with six 100% cotton t-shirts and asked them to put on a fresh t-shirt each night before going to bed. Participants then wore each shirt overnight and throughout their workday the following day (16-20 hours), placed the shirt in a ziplock bag, and placed their shirt in their freezer. Participants collected shirts in their home freezers for the duration of the odor donation period, then brought them in to the lab where they were stored in a -80°C freezer to preserve the odors (Lenochova, Roberts, & Havlicek, 2009). For the first three days of odor collection, participants donated *natural* body odor (devoid of any fragrances). For the final three days, participants were assigned one of two perfumes created specifically for the study (see 2.4.) in order to create our perfume/body odor blends. Participants were instructed to apply a single spray of perfume to the center of their chests and the corresponding area on their upper back, once at night before putting their shirt on, and once in the morning before starting their day (participants removed their shirt, reapplied perfume, and put the shirt back on). We received a total of six shirts from each donor: three containing natural body odor and three with their perfume/body odor blends. T-shirts were assessed by experimenters to ensure that there was a detectable odor and that no outside odor influences were apparent.

2.4. Perfumes. Perfumes were created by the experimenter and rated during pilot studies to be unfamiliar (mean=1.5 on a scale from 1-7) and mildly pleasant (mean=4.5/7). We used two different perfumes in order to ensure that results were not due to the fragrance used. For odor conditioning with perfume/body odor blends, both odor donors whose odors were used in the conditioning paradigm wore *the same perfume*. This allowed us to assess whether underlying individual differences in body odor were preserved in the presence of perfume. Perfumes were created by soaking odor-impregnated Viscopearls™ obtained from the KAO company (KAO, Tokyo, Japan) in ethanol for three days. The resulting infusion, with the Viscopearls™ removed, was distributed to participants in small spray bottles. Fragrance A consisted of a mix of hinoki (37%), kyara (24.7%), galbanum (18.5%), vanilla (9.9%), and apple (9.9%). Fragrance B contained pepper (35.3%), chamomile, lemongrass, and raspberry (17.6% each), and patchouli (11.8%).

2.5. Odor stimuli. Each participant smelled body odors from two donors, either with or without perfume. In preparation for use, t-shirts were cut into four quadrants. Experimenters removed the bottom of the shirt approximately three inches below the armpit, and also removed the collar and sleeves. The resulting front and back portion were split in half to yield four samples per shirt. Each sample therefore included a portion of the axillary area as well as olfactory information from either the chest or upper back. A single sample was used for each participant, then discarded at the end of the experimental session. Shirt quadrants were removed from the freezer 30 minutes before participants arrived at the lab. Shirt quadrants were matched so that samples from both donors were from the same quadrant (i.e., left front for both donor 1 and donor 2). Each quadrant was cut in half before being placed in the olfactometer (see 2.6.) for use during the 3AFC and conditioning tasks.

Odor donors were paired such that donor 1 was always presented with donor 2 (pair 1), in both the perfume and natural body odor conditions, and donor 3 was always presented with donor 4 (pair 2). Pair 1 wore perfume A and pair 2 wore perfume B. Designation of which donor was the conditioned and which was the control was counterbalanced across participants, as was the donor pair that each participant smelled.

2.6. Odor delivery and computer presentation of visual stimuli. Odors were delivered birhinally by a temporally precise, custom-built olfactometer (Lundström, Gordon, Alden, Boesveldt, & Albrecht, 2010). The odor delivery cannula were attached to a chest strap to circumvent the need for an uncomfortable chin rest (see Figure 1). T-shirt samples (both halves of the quadrant) were placed in glass jars with Teflon lids. Odor onset timing was regulated by E-Prime Professional 2.0 (Psychological Software Tools, Sharpsburg, PA). Odors were delivered at a flow rate of 1.5 L/m, and clean air was delivered at the same rate between trials to minimize odor residuals. Participants viewed all instructions, questions, and odor-onset cues on a computer monitor, and indicated their responses with the computer mouse. Presentation of visual information was also regulated by E-Prime, and was time-locked to odor presentations.

Figure 1. Odor delivery apparatus attached to chest strap (A) and electrodes for GSR collection (B).

2.7. Physiological measures. Galvanic skin response (GSR) was recorded throughout the 3AFC and conditioning session as an objective measure of learning (Flykt, Esteves, & Öhman, 2007). GSR was recorded continuously by LabChart Pro, Version 7 (ADInstruments, Colorado Springs, CO). Responses were collected from the palmar surface of the pointer and ring fingers of participants' left hands, as the right hand was engaged in using the computer mouse (see figure 1). We used 10mm Ag/AgCl round electrodes with a sampling rate of 100Hz and a high-pass filter of 0.1Hz (Andreassi, 2000).

2.8. Participant setup. When participants arrived at the lab, they were given consent forms and led to believe that the main focus of the study was "learning and the sense of smell." Participants were told that they needed to wear a lab coat during all portions of the study to protect equipment from any odors on their clothing. In practice, we used this as an opportunity to acclimate them to wearing a coat so that we could embed odors in the coats worn during the face rating trials (see section 2.12). Following the 3AFC (section 2.9) and conditioning paradigm (2.11), participants were asked if they would be willing to participate in a "pilot study." The experimenter explained that the lab was planning to use some photos of faces in an upcoming study, and needed to ensure that the faces chosen received similar emotional ratings. As such, the lab needed participants to rate a series of faces in order to help them choose the ones that were best matched. No participant declined to participate.

2.9. Three alternative forced choice task. Prior to the conditioning paradigm, participants completed six trials of a three-alternative forced choice task (3AFC), using an "odd man out" strategy, which experimenters explained was a measure of their baseline ability to discriminate between the two odors used in the "learning task" (conditioning paradigm). Two odor presentations were of the same odor, while one was of a different odor. Participants were asked to identify which presentation contained the odd odor. Following conditioning, participants completed the same 3AFC task in order to monitor any changes in conscious stimulus discrimination as a result of the conditioning, which experimenters explained was to assess learning in the conditioning paradigm.

2.10. Shock. 200ms-long square-wave electric pulses were administered to the palmar surface of the ring and pinkie fingers of the right hand, using 10mm Ag/AgCl round electrodes, which were attached following the completion of the 3AFC. Shock delivery was controlled by ADInstruments and was timelocked with olfactory presentations via LabChart. Shock level was determined individually for each participant, with a range of 0.5mA-10mA. Participants were asked to choose a level of shock that was uncomfortable but not unbearable – approximately a 7 on a scale from 1 to 10. Beginning with a 0.5mA shock, the experimenter increased the stimulus level in a stepwise fashion in intervals of 0.5mA until participants reported reaching the 7/10 discomfort threshhold.

2.11. Aversive conditioning paradigm. Each participant smelled body odors from one pair of odor donors. The designation of which donor's odor was paired with shock (conditioned stimulus - CS) and which was not (control) was counterbalanced across participants. Participants smelled either both donors' natural body odor, or both donors wearing the same perfume. They began the conditioning segment with four unshocked training trials to ensure that they were familiar with the procedure for odor rating. Then participants completed a total of 40 odor trials (20 of each odor) in a pseudorandomized order with a 50% reinforcement rate for the CS, for a total of 10 shocks over the course of the experiment. Order of presentation was set to ensure that shocks were equitably distributed throughout the first and second half of trials, and that participants received no more than two shocks in a row. At the beginning of each trial, participants saw a black fixation cross, which turned green just before the odor was presented. They then received a 4s odor presentation, paired during the last

200ms with a shock if there was one (10 of 20 CS trials). Following each odor presentation, participants were asked to rate the pleasantness and intensity of the odor, as well as how anxious they were feeling, using visual-analog scales anchored with "not at all" and "very much".

2.12. Face rating paradigm. Following the conditioning paradigm, the experimenter asked participants whether they were willing to participate in the face rating "pilot study." Once they agreed, they were told they would have a five-minute restroom break before the face rating portion began. Participants were led to a waiting room with access to a restroom, and remained there while experimenters removed the odor samples from the olfactometer and pinned them inside the lapels of two identical lab coats (one coat with the CS and one with the control odor) (see Figure 2). When participants were escorted back to the room, they were given the lab coat containing one of the odors, in a counterbalanced fashion. Participants wore this coat for the duration of the first set of face ratings, then returned to the waiting room for a second five-minute break, auspiciously to allow them to refresh their eyes before a second round of face ratings. When participants returned to the testing room, they were given the lab coat containing the second odor. No participant questioned the need for the lab coat, noticed the t-shirt samples hidden in the lapels, or noticed the transition between lab coats during the experiment.

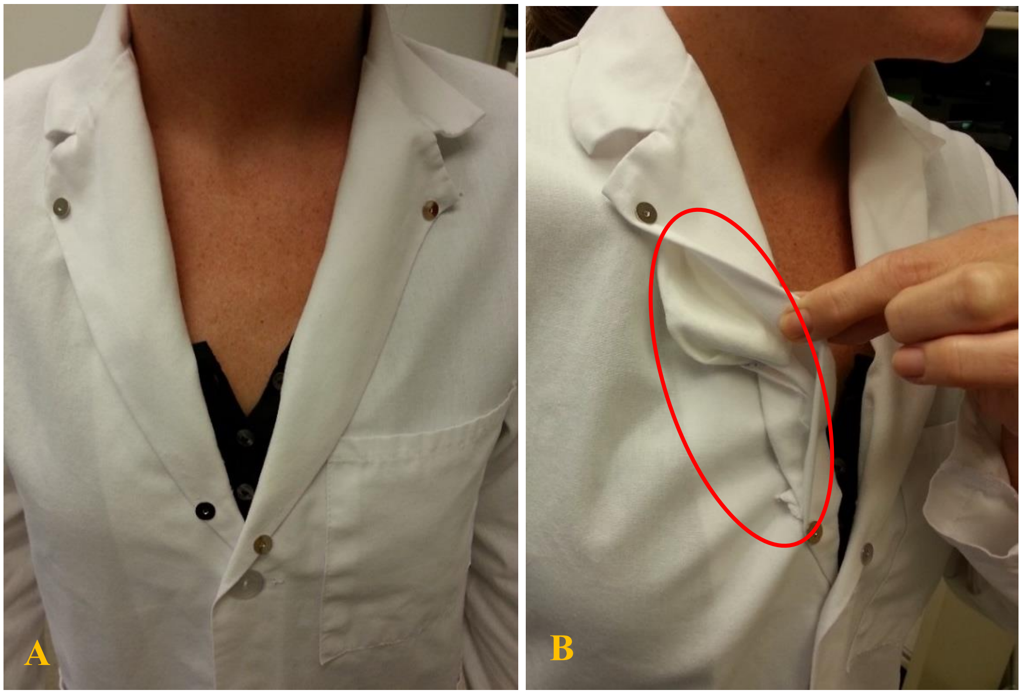

Figure 2. Lab coat with hidden odor samples for odor presentation during the face rating task, as presented to participants (A) and with t-shirt sample visible (B).

The full set of faces consisted of 33 female faces displaying neutral expressions, obtained from the Karolinska Directed Emotional Faces Database (Karolinska Institute, Stockholm, Sweden). On each face rating trial, participants viewed a fixation cross and then a 250ms presentation of a face. Following the face presentation, participants were asked to rate, on separate but consecutive screens, how happy, fearful, anxious, sad, angry, and surprised the most recent face was, using visual-analog scales anchored by "not at all" and "very much". Because we were interested in capturing automatic responses to the faces, we chose to keep the order of the emotions rated constant across trials, rather than randomizing them.

3. Results

3.1. Physiological results. We first calculated the GSR response for each odor presentation by subtracting the mean of the GSR during the 1s before odor onset from the maximum GSR in the 10s post-odor onset. This allowed us to calculate the increase in GSR following odor presentation above the baseline GSR displayed by the participant between odor trials. We normalized (z-transformed) these difference scores within each subject, then eliminated any responses more than +/-3 standard deviations from the mean. All analyses were conducted using R version 3.1.2.

We used a linear mixed effects model with Satterthwaite approximations to degrees of freedom to assess the difference in GSR between conditioned odor presentations with a shock and those without. We fit the model with the lme4 (Bates, Maechler, Bolker, & Walker, 2015) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2016) packages. We reasoned that if participants were learning to anticipate a shock with the onset of the conditioned odor, we would see a resulting increase in GSR even when no shock was presented. Therefore, our model included odor presentation type (cs+ to denote conditioned odor trials where participants received a shock, cs- to denote conditioned odor trials where participants did *not* receive a shock, or control), perfume condition (natural body odor or body odor+perfume), donor pair, order of presentation (first half of trials vs. second half of trials), and an interaction of odor type and order of presentation as fixed effects, and rater ID as a random effect. We found no effect of donor pair ($F_{3,1648}$=.32, p=.811) or perfume condition ($F_{1,1648}$=.14, p=.705). We did find a significant effect of the interaction between order of presentation and odor type ($F_{2,1648}$=3.28, p=.038).

We then used the lsmeans package (Lenth, 2015, 2016) for post-hoc pairwise comparisons to examine whether there were differences in the GSR between the control odor and the unshocked conditioned odor presentations. We calculated the least squares means estimates for the six combinations of presentation type and presentation half, averaged over the levels for perfume condition and donor pair. We compared estimates that shared either a common presentation half or a common presentation type and corrected for multiple comparisons with a false discovery rate (FDR). We found that there was a significant difference between the CS- and the control trials in the second half of odor presentations ($t_{1613}=2.1$, adjusted $p=.0405$) but we found no difference in the first half ($t_{1614}=1.32$, adjusted $p=.18$), suggesting that participants learned to anticipate a shock on CS odor trials in the second half of training (see Figure 3).

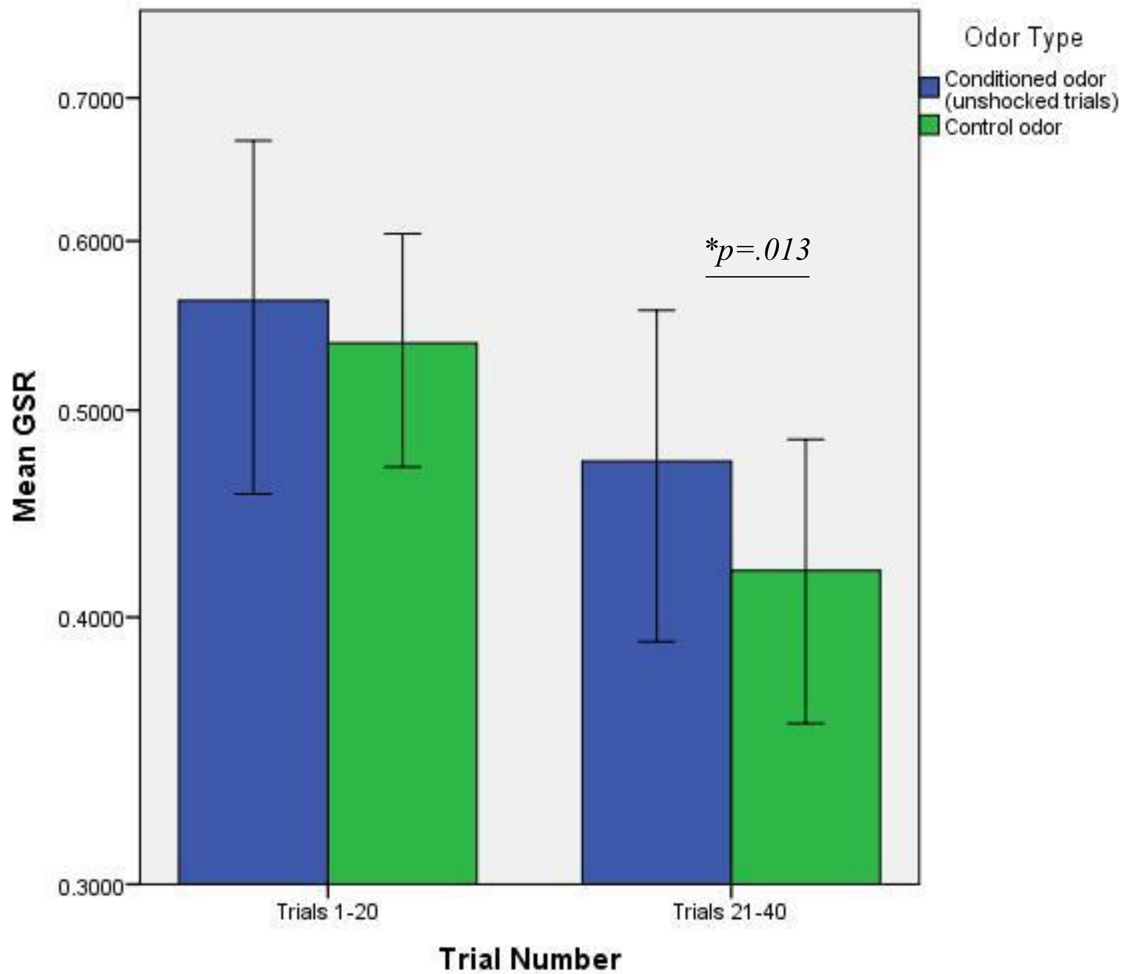

Figure 3. Evidence of successful conditioning. Mean galvanic skin response (GSR) scores for conditioned odor trials where the odor was presented with no shock (50% of conditioned odor trials) and control odors trials where the control odor was never paired with shock. Results show that for the second half of trials, GSR response to the unshocked conditioned odor presentations was significantly higher than GSR response to the control trials, providing evidence that participants learned to anticipate a shock when presented with the conditioned odor but not the control.

3.2. Behavioral results. We ran a linear mixed effects model of log transformed ratings, again using the lmerTest package (Kuznetsova et al., 2016) in R version 3.1.2. We included fixed effects of emotion rated, odor type (BO or BO+perfume), and odor condition (CS or control) as well as all two-way interactions.

We also controlled, using fixed effects, for position within trials in a session (was the participant rating the first face or the 33rd), round number (first or second round of ratings), and whether samples used for odor stimuli were taken from the front or back of the shirt. We used random effects to control for which image was viewed, subject ID, and trial within subject. We found a significant effect for odor condition ($F_{1, 15925.3}$=5.069, *p*=.0244) as well as a significant interaction between emotion rated and odor type ($F_{5, 15925}$=3.464, *p*=.0039). Additionally, we found a significant effect of position within trials ($F_{1, 1402.6}$=23.259, *p*<.001), which likely pertains to participants' increasing boredom as the task progressed.

We then used the lsmeans package (Lenth, 2016) to investigate the relationship among emotion rated, odor condition, and odor type. We conduct pairwise comparisons of the predicted rating for odor condition (CS or control) and odor type (BO or BO+perfume) grouped within each emotion, using a Tukey correction for multiple hypothesis tests based on a family of four means within each task. We found a significant difference in the ratings of surprise depending on odor condition such that the difference between ratings of surprise in the presence of the CS were higher than the ratings of surprise in the presence of the control odor for both BO (z_x=.3.674, *p*=.0014) and BO+perfume (z_x=3.128, *p*=.0096). We found no significant differences between ratings made in the presence of the CS and ratings made in the presence of the control for any other emotion (all *p*s>.35) (see Figure 4).

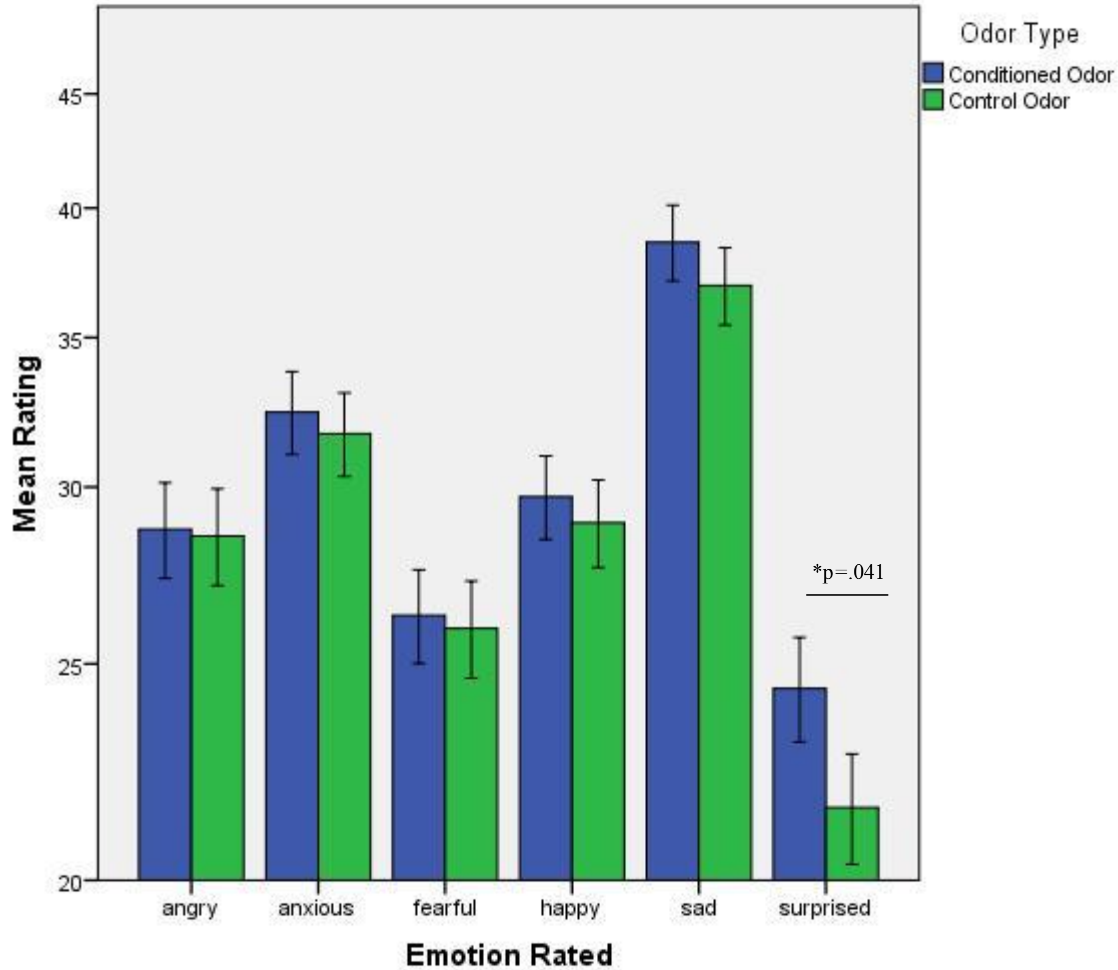

Figure 4. Olfactory information influences visual perception: mean emotion ratings for neutral faces in the presence of the aversively conditioned odor (blue) and the control odor (green). Ratings of surprise were significantly higher in the presence of the conditioned odor than the control odor.

We used the same model formats to examine differences in participant's reaction times during the face rating task. We found significant interactions between emotion rated and odor type ($F_{5,\,15918.2}$=7.97, p<.001) and between odor type and odor condition ($F_{1,\,15918.2}$=4.74, p=.029). We also found significant effects for position within trials ($F_{1,\,1403.3}$=437.79, p<.001) and round number ($F_{1,\,15918.2}$=738.15, p<.001).

When we examined the pairwise comparisons, we found no significant differences between reaction times in the presence of the CS and reaction times in the presence of the control (all p's>.245).

4. Discussion

In this study, we aimed to clarify the role of perfume in social olfactory communication. We set out to investigate whether perfumes affect the communication of individual identity by answering three main questions: 1) is it possible to use a classical aversive conditioning paradigm to elicit a negative emotional reaction to an individual body odor, 2) does perfume modify the effectiveness of classical conditioning using body odors, and 3) does the presence of an aversively conditioned body odor affect social perception in a visual task?

We found that body odors are acceptable candidates for use as stimuli in a classical aversive conditioning paradigm, as evidenced by participants' learned aversions to body odors paired with shock. To the best of our knowledge, this is the first time that body odors have been used in this manner. We further found that the potential for creating this learned aversion to an individual's odor is not affected by the presence of perfume. Importantly, this result suggests that perfume does not inhibit the perception of individual identity in body odor. If perfume had masked individual differences, then participants would not have been able to discriminate between the perfumed body odors of two individuals sufficiently to develop a learned aversion to one but not the other. This finding supports previous research indicating that discrimination of individual identity remains intact despite the use of fragranced products (Allen et al., 2015; Lenochová et al., 2012).

We also found that the presence of an aversively conditioned body odor shifted participants' estimations of the surprise displayed in a series of neutral faces. As human social interactions are inherently multimodal, this result provides insight into the potential role of olfactory information in multimodal encounters, suggesting that olfactory information may influence social perception in other modalities.

We suggest that the increased perception of surprise might be due to increased vigilance in the presence of the conditioned odor. Humans tend to mirror the emotions displayed by others (Sato & Yoshikawa, 2007), and these mirrored facial expressions have been proposed to facilitate emotional recognition, particularly in the case of ambiguous or weak emotional displays (Hess & Blairy, 2001). Increased arousal and vigilance are typically displayed in facial expressions that include widened eyes and flared nostrils, expressions also shared by those who are surprised (Ekman, Friesen, & Ellsworth, 2013). During debriefing, participants consistently noted that they were unaware of the odor manipulation during the face rating task. In the absence of any concrete display of emotion from the neutral faces, it is possible that participants were misattributing their own expressions of increased vigilance – due to the unconscious perception of the conditioned odor – to the perception of surprise in the faces they were viewing.

Taken together, the results of this study suggest that body odor can evoke a learned response following emotional experiences with that odor. Given the tendency for associative learning to create strong, emotional memories for non-human odors (Herz, 2011), combined with the fact that humans show the clear ability to learn and discriminate the odor signatures of both familiar (Mallet & Schaal, 1998; Olsson et al., 2006; Porter et al., 1986) and unfamiliar (Allen et al., 2015; Porter, Cernoch, & Balogh, 1985) individuals, we suggest that body odor as it is experienced in a normal social interaction may act as a memory facilitator. In other words, sharing experiences with an individual – in the necessary presence of his or her body odor – allows us to pair emotional outcomes with that body odor, essentially creating a conditioned response to that particular individual. As a result, smelling the body odor of a familiar other may be pleasant and comforting if you have shared positive experiences, such as those with a mother, partner or friend (McBurney, Shoup, & Streeter, 2006; Rattaz, Goubet, & Bullinger, 2005; Shoup, Streeter, & McBurney, 2008). Conversely, smelling the body odor of a familiar other with whom you have shared unpleasant experiences (an ex-boyfriend, perhaps), will evoke a negative emotion. Over time, these learned associations may help us to decide in which relationships to continue investing time and energy, with body odor acting as a positive reinforcement when we encounter those individuals with whom we have good relationships. The increased prevalence of body contact such as kissing and hugging when greeting more intimate friends and partners may provide us with the opportunity to sample their body odor and be reminded of the good feelings we have towards them (Frumin et al., 2015; Hughes, Harrison, & Gallup, 2007; Nicholson, 1984), enhancing our further social interactions with increased prosocial behavior and affection.

4.1. Limitations. Because we used only aversive conditioning to look at learned responses to body odor, we cannot generalize these results to positive or neutral social interactions. The majority of interactions, particularly with strangers, are likely to be neutral or mildly positive, and though this experiment suggests that these interactions can serve as learning events, we cannot comment on the effectiveness of positive or neutral events in facilitating friendship formation. Though odors have successfully been used in past aversive conditioning paradigms (Åhs et al., 2013; Li et al., 2008), little research focuses on appetitive conditioning using odors as the unconditioned stimulus.

Further, as we used only female participants smelling female body odors, we cannot generalize our results to males. Though males are capable of perceiving body odors (e.g., Gildersleeve, Haselton, Larson, & Pillsworth, 2012), they tend to attribute less importance to body odor, particularly in romantic relationships (Herz & Inzlicht, 2002). As both men and women find the body odor of their partners comforting (McBurney et al., 2006), it does seem likely that men employ similar associative learning techniques during exposure to their partner's body odor. We might therefore expect to see similar patterns of aversive learning using male participants.

4.2. Future Directions. Though we show that conditioned olfactory stimuli affect visual processing, real social interactions are much more dynamic than viewing static photographs. Future research might investigate the effect of aversively conditioned body odors on perception of dynamic videos in order to gain better insight into how these odors affect facial processing in real time. Though it was not possible within the time allotted for completing this project, one of our considered aims was to extend our study not just to the perception of videos, but to perception in live social interactions. We intended to use body odors collected from confederates as the training odors in our aversive learning paradigm, and then to have participants meet these confederates in a series of structured social interactions involving simple teamwork. By videotaping these interactions and coding the nonverbal behavior of participants toward a confederate whose body odor was associated with a shock (compared to a control confederate whose body odor was never associated with shock), we hoped to ascertain whether body odor as broadcast from a live person was sufficiently perceptible to shift social perceptions in real life interactions based on emotional associations with that body odor. Simply showing that the phenomenon can be evoked in a structured, unimodal laboratory setting does not guarantee that it is available in ecologically relevant interactions. By using live interactions, we hoped to clarify the relationship between these two methods of evaluation.

4.3. Conclusion. In investigating the role of perfumed body odor in human social interactions, we found that perfume did not interfere with the perception of individual identity. We established this by showing that participants successfully learned to associate a negative outcome with the presentation of a conditioned body odor, regardless of the presence or absence of perfume in the body odors used. Further, we found that, once an aversive reaction to a body odor was established, the presence of that body odor during a visual face rating task shifted the perceived surprise in neutral faces. Our study provides evidence that body odors may serve as associative cues during the course of a relationship, gaining positive or negative valence over repeated emotional experiences with each person. We suggest that future research investigate this possibility more closely, through examination of olfactory influence on both dynamic visual stimuli and real life interactions. It seems that, after all, actions smell louder than words.

References

Åhs, F., Miller, S. S., Gordon, A. R., & Lundström, J. N. (2013). Aversive learning increases sensory detection sensitivity. *Biological Psychology*, *92*(2), 135–141. http://doi.org/10.1016/j.biopsycho.2012.11.004

Allen, C., Cobey, K. D., Havlíček, J., & Roberts, S. C. (2016). The impact of artificial fragrances on the assessment of mate quality cues in body odor. *Evolution and Human Behavior*. http://doi.org/10.1016/j.evolhumbehav.2016.05.001

Allen, C., Havlíček, J., & Roberts, S. C. (2015). Effect of fragrance use on discrimination of individual body odor. *Frontiers in Psychology*, *6*. http://doi.org/10.3389/fpsyg.2015.01115

Andreassi, J. L. (2000). *Psychophysiology: Human Behavior and Physiological Reponse*. New York, NY: Lea.

Austin, C., & Ellis, J. (2003). Microbial pathways leading to steroidal malodour in the axilla. *Journal of Steroid Biochemistry and Molecular Biology*, *87*(1), 105–110. http://doi.org/10.1016/S0960-0760(03)00387-X

Baron, R. A. (1986). Self-Presentation in Job Interviews: When There Can Be "Too Much of a Good Thing." *Journal of Applied Social Psychology*, *16*(1), 16–28. http://doi.org/10.1111/j.1559-1816.1986.tb02275.x

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software2*, *67*(1), 1–48.

Behan, J. M., Macmaster, a P., Perring, K. D., & Tuck, K. M. (1996). Insight into how skin changes perfume. *International Journal of Cosmetic Science*, *18*(1 996), 237–246. http://doi.org/10.1111/j.1467-2494.1996.tb00154.x

Buljubasic, F., & Buchbauer, G. (2014). The scent of human diseases: A review on specific volatile organic compounds as diagnostic biomarkers. *Flavour and Fragrance Journal, 30 (1)*(August 2014), 5–25. http://doi.org/http://dx.doi.org/10.1002/ffj.3219

Cantafio, L. C. (2003). *Human Olfactory Communication of Alarm and Safety*. Rutgers University. Retrieved from UMI Number: 3077089

Chen, D., & Haviland-Jones, J. (2000). Human olfactory communication of emotion. *Perceptual and Motor Skills*, *91*(3 Pt 1), 771–81. http://doi.org/10.2466/pms.2000.91.3.771

de Groot, J. H. B., Smeets, M. a. M., Rowson, M. J., Bulsing, P. J., Blonk, C. G., Wilkinson, J. E., & Semin, G. R. (2015). A Sniff of Happiness. *Psychological Science*, (April), 0956797614566318-. http://doi.org/10.1177/0956797614566318 de Groot, J. H. B., Smeets, M. a M., Kaldewaij, A., Duijndam, M. J. a, & Semin, G. R. (2012). Chemosignals communicate human emotions. *Psychological Science*, *23*(11), 1417–24. http://doi.org/10.1177/0956797612445317

Ekman, P., Friesen, W. V., & Ellsworth, P. (2013). *Emotion in the Human Face: Guidelines for Research and an Integration of Findings*. Elsevier.

Flykt, A., Esteves, F., & Öhman, A. (2007). Skin conductance responses to masked conditioned stimuli: Phylogenetic/ontogenetic factors versus direction of threat? *Biological Psychology*, *74*(3), 328–336. http://doi.org/10.1016/j.biopsycho.2006.08.004

Frumin, I., Perl, O., Endevelt-Shapira, Y., Eisen, A., Eshel, N., Heller, I., … Sobel, N. (2015). A social chemosignaling function for human handshaking. *eLife*, *4*, e05154. http://doi.org/10.7554/eLife.05154

Gildersleeve, K. A., Haselton, M. G., Larson, C. M., & Pillsworth, E. G. (2012). Body odor attractiveness as a cue of impending ovulation in women: Evidence from a study using hormone-confirmed ovulation. *Hormones and Behavior*, *61*(2), 157–166. http://doi.org/10.1016/j.yhbeh.2011.11.005

Guéguen, N. (2001). Effect of a perfume on prosocial behavior of pedestrians. *Psychological Reports*, *88*(3 Pt 2), 1046–8. http://doi.org/10.2466/pr0.2001.88.3c.1046

Hämmerli, A., Schweisgut, C., & Kaegi, M. (2012). Population genetic segmentation of MHC-correlated perfume preferences. *International Journal of Cosmetic Science*, *34*(2), 161–168. http://doi.org/10.1111/j.1468-2494.2011.00696.x

Havlíček, J., Dvořáková, R., Bartoš, L., & Flegr, J. (2006). Non-advertized does not mean concealed: Body odour changes across the human menstrual cycle. *Ethology*, *112*(1), 81–90. http://doi.org/10.1111/j.1439-0310.2006.01125.x

Havlíček, J., & Roberts, S. C. (2013). The Perfume-Body Odour Complex : An Insightful Model for Culture – Gene Coevolution ? In *Chemical Signals in Vertebrates 12* (pp. 185–195). New York, NY: Springer. http://doi.org/10.1007/978-1-4614-5927-9

Herz, R. S. (2011). Perfume. In J. A. Gottfried (Ed.), *Neurobiology of Sensation and Reward* (p. Chapter 17). Boca Raton, FL: CRC Press/Taylor & Francis.

Herz, R. S., & Inzlicht, M. (2002). Sex differences in response to physical and social factors involved in human mate selection. The importance of smell for women. *Evolution and Human Behavior*, *23*(5), 359–364. http://doi.org/10.1016/S1090-5138(02)00095-8

Hess, U., & Blairy, S. (2001). Facial mimicry and emotional contagion to dynamic emotional facial expressions and their influence on decoding accuracy. *International Journal of Psychophysiology*, *40*, 129–141. http://doi.org/10.1016/S0167-8760(00)00161-6

Higuchi, T., Shoji, K., Taguchi, S., & Hatayama, T. (2005). Improvement of nonverbal behaviour in Japanese female perfume-wearers. *International Journal of Psychology*, *40*(February 2012), 90–99. http://doi.org/10.1080/00207590444000050

Hughes, S. M., Harrison, M. a, & Gallup, G. G. J. (2007). Sex differences in romantic kissing among college students: An evolutionary perspective. *Evolutionary Psychology*, *5*(3), 612–631. http://doi.org/10.1177/147470490700500310

Jacob, S., McClintock, M. K., Zelano, B., & Ober, C. (2002). Paternally inherited HLA alleles are associated with women's choice of male odor. *Nature Genetics*, *30*(2), 175–179. http://doi.org/10.1038/ng830

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2016). lmerTest: Tests in linear mixed effects models. R Package Version 2.0-32. Retrieved from https://cran.r-project.org/package=lmerTest

Lenochova, P., Roberts, S. C., & Havlicek, J. (2009). Methods of human body odor sampling: The effect of freezing. *Chemical Senses*, *34*(2), 127–138. http://doi.org/10.1093/chemse/bjn067

Lenochová, P., Vohnoutová, P., Roberts, S. C., Oberzaucher, E., Grammer, K., & Havlíček, J. (2012). Psychology of fragrance use: Perception of individual odor and perfume blends reveals a mechanism for idiosyncratic effects on fragrance choice. *PLoS ONE*, *7*(3), 1–10. http://doi.org/10.1371/journal.pone.0033810

Lenth, R. V. (2015). Using lsmeans, 1–34.

Lenth, R. V. (2016). Least-squares means: The R package lsmeans. *Journal of Statistical Software*, *69*(1), 1–33.

Li, W., Howard, J. D., Parrish, T. B., & Gottfried, J. A. (2008). Aversive Learning Enhances Perceptual and Cortical Discrimination of Indiscriminable Odor Cues. *Science*, *319*(5871), 1842–1845. http://doi.org/10.1126/science.1152837.Aversive

Lübke, K. T., Hoenen, M., & Pause, B. M. (2012). Differential processing of social chemosignals obtained from potential partners in regards to gender and sexual orientation. *Behavioural Brain Research*, *228*(2), 375–387. http://doi.org/10.1016/j.bbr.2011.12.018

Lundström, J. N., Boyle, J. A., Zatorre, R. J., & Jones-Gotman, M. (2008). Functional neuronal processing of body odors differs from that of similar common odors. *Cerebral Cortex*, *18*(6), 1466–1474. http://doi.org/10.1093/cercor/bhm178

Lundström, J. N., Boyle, J. A., Zatorre, R. J., & Jones-Gotman, M. (2009). The neuronal substrates of human olfactory based kin recognition. *Human Brain Mapping*, *30*(8), 2571–2580. http://doi.org/10.1002/hbm.20686

Lundström, J. N., Gordon, A. R., Alden, E. C., Boesveldt, S., & Albrecht, J. (2010). Methods for building an inexpensive computer-controlled olfactometer for temporally precise experiments. *International Journal of Psychophysiology2*, *78*(2), 179–189. http://doi.org/10.1016/j.ijpsycho.2010.07.007.Methods

Mallet, P., & Schaal, B. (1998). Rating and recognition of peers' personal odors by 9-year-old children: an exploratory study. *The Journal of General Psychology*, *125*(1), 47–64. http://doi.org/10.1080/00221309809595576

Martins, Y., Preti, G., Crabtree, C. R., Runyan, T., Vainius, A. A., & Wysocki, C. J. (2005). Preference for human body odors is influenced by gender and sexual orientation. *Psychological Science*, *16*(9), 694–701. http://doi.org/10.1111/j.1467-9280.2005.01598.x

McBurney, D. H., Shoup, M. L., & Streeter, S. A. (2006). Olfactory Comfort : Smelling a Partner ' s Clothing During. *Journal of Applied Psychology*, *36*(9), 2325–2335.

Milinski, M., & Wedekind, C. (2001). Evidence for MHC-correlated perfume preferences in humans. *Behavioral Ecology*, *12*(2), 140–149. http://doi.org/10.1093/beheco/12.2.140

Mitro, S., Gordon, A. R., Olsson, M. J., & Lundstr??m, J. N. (2012). The smell of age: Perception and discrimination of body odors of different ages. *PLoS ONE*, *7*(5). http://doi.org/10.1371/journal.pone.0038110

Natsch, A., Kuhn, F., & Tiercy, J. M. (2010). Lack of evidence for HLA-linked patterns of odorous carboxylic acids released from glutamine conjugates secreted in the human axilla. *Journal of Chemical Ecology*, *36*(8), 837–846. http://doi.org/10.1007/s10886-010-9826-y

Nicholson, B. (1984). Does kissing aid human bonding by semiochemical addiction? *The British Journal of Dermatology*, *111*(5), 623–627. http://doi.org/10.1111/j.1365-2133.1984.tb06635.x

Olsson, M. J., Lundström, J. N., Kimball, B. a, Gordon, A. R., Karshikoff, B., Hosseini, N., … Lekander, M. (2014). The scent of disease: human body odor contains an early chemosensory cue of sickness. *Psychological Science*, *25*(3), 817–23. http://doi.org/10.1177/0956797613515681

Olsson, S. B., Barnard, J., & Turri, L. (2006). Olfaction and identification of unrelated individuals: Examination of the mysteries of human odor recognition. *Journal of Chemical Ecology*, *32*(8), 1635–1645. http://doi.org/10.1007/s10886-006-9098-8

Parma, V., Ferraro, S., Miller, S. S., Åhs, F., & Lundström, J. N. (2015). Enhancement of odor sensitivity following repeated odor and visual fear conditioning. *Chemical Senses*, *40*(7), 497–506. http://doi.org/10.1093/chemse/bjv033

Pause, B. M. (2012). Processing of Body Odor Signals by the Human Brain. *Chemosensory Perception*, *5*(1), 55–63. http://doi.org/10.1007/s12078-011-9108-2

Pause, B. M., Krauel, K., Schrader, C., Sojka, B., Westphal, E., Müller-Ruchholtz, W., & Ferstl, R. (2006). The human brain is a detector of chemosensorily transmitted HLA-class I-similarity in same- and opposite-sex relations. *Proceedings. Biological Sciences / The Royal Society*, *273*(1585), 471–478. http://doi.org/10.1098/rspb.2005.3342

Penn, D. J., Oberzaucher, E., Grammer, K., Fischer, G., Soini, H. A., Wiesler, D., … Brereton, R. G. (2007). Individual and gender fingerprints in human body odour. *Journal of the Royal Society, Interface / the Royal Society*, *4*(13), 331–40. http://doi.org/10.1098/rsif.2006.0182

Porter, R. H., Balogh, R. D., Cernoch, J. M., & Franchi, C. (1986). Recognition of kin through characteristic body odors. *Chemical Senses*, *11*(3), 389–395. http://doi.org/10.1093/chemse/11.3.389

Porter, R. H., Cernoch, J. M., & Balogh, R. D. (1985). Odor signatures and kin recognition. *Physiology and Behavior*, *34*(3), 445–448. http://doi.org/10.1016/0031-9384(85)90210-0

Prehn-Kristensen, A., Wiesner, C., Bergmann, T. O., Wolff, S., Jansen, O., Mehdorn, H. M., … Pause, B. M. (2009). Induction of empathy by the smell of anxiety. *PloS One*, *4*(6), e5987. http://doi.org/10.1371/journal.pone.0005987

Rattaz, C., Goubet, N., & Bullinger, A. (2005). The calming effect of a familiar odor on full-term newborns. *Journal of Developmental and Behavioral Pediatrics : JDBP*, *26*(2), 86–92. http://doi.org/10.1097/00004703-200504000-00003

Roach, J. (2007). Oldest Perfumes Found on "Aphrodite's Island." Retrieved from http://news.nationalgeographic.com/news/2007/03/070329-oldest-perfumes.html

Roberts, S. C., Little, C., Lyndon, A., Roberts, J., Havlicek, J., & Wright, R. L. (2009). Manipulation of body odour alters men's self-confidence and judgements of their visual attractiveness by women. *International Journal of Cosmetic Science*, *31*(1), 47–54. http://doi.org/10.1111/j.1468-2494.2008.00477.x

Sato, W., & Yoshikawa, S. (2007). Spontaneous facial mimicry in response to dynamic facial expressions. *Cognition*, *104*(1), 1–18. http://doi.org/10.1016/j.cognition.2006.05.001

Shoup, M. L., Streeter, S. A., & McBurney, D. H. (2008). Olfactory comfort and attachment within relationships. *Journal of Applied Social Psychology*, *38*(12), 2954–2963. http://doi.org/10.1111/j.1559-1816.2008.00420.x

Thornhill, R. (1999). The Scent of Symmetry A Human Sex Pheromone that Signals Fitness? *Evolution and Human Behavior*, *20*(3), 175–201. http://doi.org/10.1016/S1090-5138(99)00005-7

Troccaz, M., Gaïa, N., Beccucci, S., Schrenzel, J., Cayeux, I., Starkenmann, C., & Lazarevic, V. (2015). Mapping axillary microbiota responsible for body odours using a culture-independent approach. *Microbiome*, *3*, 3. http://doi.org/10.1186/s40168-014-0064-3

Willander, J., & Larsson, M. (2007). Olfaction and emotion: the case of autobiographical memory. *Memory & Cognition*, *35*(7), 1659–1663. http://doi.org/10.3758/BF03193499

Zhou, W., & Chen, D. (2011). Entangled chemosensory emotion and identity: familiarity enhances detection of chemosensorily encoded emotion. *Social Neuroscience*, *6*(3), 270–276. http://doi.org/10.1080/17470919.2010.523537

Zuniga, A., Stevenson, R. J., Mahmut, M. K., & Stephen, I. D. (2016). Diet quality and the attractiveness of male body odor. *Evolution and Human Behavior*. http://doi.org/10.1016/j.evolhumbehav.2016.08.002

CHAPTER 4

DOES THE NOSE SMELL WHAT THE EYES SEE? OLFACTORY AND VISUAL INFLUENCES ON MULTIMODAL SOCIAL INTERACTIONS

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Abstract

Does body odor influence our first impressions of others? Though much is known about how visual information affects first impressions, surprisingly little research has examined how a person's body odor might affect a first meeting with an unknown other. Natural body odor contains a number of social cues, including information about emotional state, health, gender, and sexual orientation. Most social olfactory research has focused on natural axillary (armpit) odors collected on *t*-shirts, devoid of any outside fragrance or deodorant, which bear little resemblance to the way that we interact with body odor in real life, on whole bodies. In particular, these studies fail to consider what we term *diplomatic odor* - the modified body odor that most people present in daily life, which includes influences from fragrances, deodorants, and dietary choices. In this study, we assessed the extent to which women's unimodal first impressions, based on diplomatic odor samples collected on *t*-shirts and facial photographs of other women, predicted liking of those same individuals during a live, multimodal interaction using a speed dating-based "speed friending" paradigm. We found that while visual first impressions based on photographs strongly predicted first impressions in the speed friending task, olfactory first impressions based on t-shirts did not. Visual-based judgments did not predict olfactory-based judgments, though olfactory-based judgments were consistent across multiple assessments. These findings suggest that, although participants display reliable olfactory preferences in unimodal assessments, in brief multimodal interactions with strangers, visual judgments take precedence.

1. Introduction

Human interactions are inherently multimodal. We know that visual and auditory information are important in informing first impressions of others, but what role, if any, does olfactory information play? Though we know that human body odor contains a number of social cues, little research has examined whether these cues are perceptible in real life, every day social interactions. In this paper, we aim to examine how diplomatic body odor – a person's scent during regular application of deodorant, perfume, and other scented products – influences interpersonal social judgments in a live interaction. Specifically, the study aims to address three questions using the same set of female participants: (1) how do first impressions of others based on exposure to diplomatic olfactory cues collected on cotton *t*-shirts relate to first impressions following a live interaction with the same person? (2) how do first impressions based on photographs of a woman's face and hair only relate to first impressions following a live interaction with the same person? And (3) how do these *t*-shirt-based judgments relate to judgments based on photographs? That is, what are the relative contributions of olfactory- and visual-based judgments to first impressions?

It is well established that human olfactory signals can communicate information related to health and mate fitness (Olsson et al., 2014; Roberts et al., 2011), emotion (de Groot et al., 2015; Haviland-Jones, McGuire, & Wilson, 2016; Prehn-Kristensen et al., 2009), and individual identity (reviewed in Lenochová & Havlicek, 2008). In the majority of human social olfactory research, participants are asked to smell samples of "natural," unmodified axillary sweat during experiments. Odor *donors* in these studies are typically asked to wear t-shirts or cotton pads in their armpits to collect their axillary sweat. During the donation process, donors are asked to deliberately refrain from engaging in everyday routines known to affect body odor, such as wearing perfumes or deodorant, consuming aromatic foods or alcohol, and holding pets. Rather, these odor donors are asked to use only fragrance-free hygiene products provided to them by experimenters. However, in real life people rarely present themselves in such a “natural” state. Most people wear deodorant, use hygiene products with added fragrances, and eat foods that may contribute to the way their body odor smells in their everyday lives. We refer to this altered body odor as *diplomatic odor*.

Very few studies have attempted to examine how perception of diplomatic body odor differs from natural body odor, and the majority of these have examined only single facets of diplomatic odor, such as personal habits or fragrances use. For example, one study on hygiene habits suggests that the shaving of armpits affects ratings of body odor pleasantness and attractiveness (Kohoutová, Rubešová, & Havlíček, 2012). Studies examining dietary choices show that increased intake of fruits and vegetables increases the perceived pleasantness of body odor (Zuniga, Stevenson, Mahmut, & Stephen, 2016) as does the consumption of raw garlic (Fialová, Lenochová, & Havlíček, 2011; Jitka Fialová, Roberts, & Havlíček, 2016), while red meat consumption decreases body odor attractiveness and pleasantness (Havlicek & Lenochova, 2006).

A handful of studies have also examined the social effects of personal fragrance choices. Three studies suggest that allowing participants to wear fragranced products of their choosing increases perceived pleasantness and attractiveness of body odor (Allen, Havlíček, & Roberts, 2015; Lenochová et al., 2012; Schleidt, 2002), though two of these studies note that fragrances may also interfere with discrimination of personal information contained in body odor such as individual identity (Allen et al., 2015) and gender (Schleidt, 2002). Recent research in our lab indicates natural body odor is perceived differently than diplomatic odor (Gaby & Zayas, in review). In these studies, we showed a dissociation between social judgments based on natural and diplomatic odor using both the traditional t-shirt collection methodology, and a novel paradigm developed in our lab for assessing human olfaction in live settings (i.e., raters are blindfolded and earplugged, and judge the body odor of another person).

Considering the dearth of studies examining the combined effects of fragrance, deodorant, hygiene choices, and diet, it is difficult to draw strong conclusions about how diplomatic odor affects everyday social interactions. Further, few studies have examined the perception of body odor in live interactions, and the majority of these have focused on men's perception of women with and without perfume (see, for example, Baron, 1986). As it is highly unusual to smell someone's armpit during the course of a normal social interaction, particularly if that other person is a stranger, using odor samples collected on t-shirts or cotton pads may not be reflective of the information one would perceive during a normal social interaction. Thus, little is known about how people's body odor in everyday life influences interpersonal judgments.

How might olfactory information relate to visual information? Previous research indicates that visual ratings of attractiveness are related to olfactory ratings of attractiveness. In one study, researchers found that for men, ratings of female visual attractiveness strongly correlated with ratings of female body odor attractiveness (Rikowski & Grammer, 1999). Women show a similar positive correlation between perceptions of men's body odor and facial attractiveness when they are at high risk of conception, but not when they are at low risk (Gangestad & Thornhill, 1998; Thornhill, 1999). Interestingly, this effect is not limited to static images – women's preferences for men's nonverbal behavior also correlates with their preferences for male body odor (Roberts et al., 2011).

One way of examining visual perception of others is asking participants to make *snap judgments*, or judgments based on very brief presentations of visual stimuli. Snap judgments of female faces have been shown to predict liking in real life interactions (Gunaydin, Selcuk, & Zayas, 2016), and snap judgments of opposite sex faces have been shown predict judgments following a live interaction in a speed dating paradigm (Cooper, Dunne, Furey, & O'Doherty, 2012). Snap judgments have also been shown to be effective predictors for sexual orientation judgments (Tabak & Zayas, 2012) and female liking of partner-similar morphed faces (Günaydin, Zayas, Selcuk, & Hazan, 2012).

`Thus far, the research in our lab has examined the perception of diplomatic odor only in unisensory situations (e.g.,blindfolded, earplugged participants smelling natural and diplomatic odor of present others or t-shirt samples). In this study, we compared snap judgments made in a visual-only task (static photos of head and hair only), judgments made in an olfactory-only task (smelling t-shirt samples), and judgments made in a live, multimodal "speed friending" task, based on a speed dating paradigm. Speed dating allows participants – generally heterosexual males and females – to assess romantic interest in potential mates by meeting with a series of individuals during very brief interactions (Finkel, Eastwick, & Matthews, 2007). As a social psychological tool, speed dating has been used to assess a number of different factors in sexual attraction including gender differences in mate selection strategies (Fisman, Iyengar, Kamenica, & Simonson, 2006; Overbeek, Nelemans, Karremans, & Engels, 2013), effects of specific physical characteristics such as facial width-to-height ratio (Valentine, Li, Penke, & Perrett, 2014), effects of perceived similarity (Tidwell, Eastwick, & Finkel, 2013), and racial preferences (Fisman, Iyengar, Kamenica, & Simonson, 2008). In the present work, we employed only heterosexual female participants, rather than mixed dyads, which allows us to look specifically at friendship and liking judgments, rather than dateability or sexual attractiveness, providing a novel perspective on the speed-dating paradigm.

Based on the links between olfactory and visual information (e.g., Roberts et al., 2011), combined with our findings showing that diplomatic odor informs social judgments (Gaby & Zayas, in review), we hypothesized that diplomatic olfactory cues influence social judgements during live interactions. Therefore, we predicted that 1) olfactory judgments of liking would predict liking in the speed friending paradigm; 2) visual-only judgments of liking would predict liking in the speed friending paradigm better than the olfactory judgments, and 3) visual-only and olfactory-only judgments would be correlated with one another.

2. Methods

2.1. Participants. Forty women ages 18-30 (mean age 21.1) participated in the study. When asked to describe their sense of smell, the majority of participants chose "my sense of smell is normal." However, six participants selected "my sense of smell is heightened (hypersensitivity)." Because these participants did not elaborate in the open-ended question asking them to describe the nature of their olfactory disorder, we believe these women likely misunderstood this option as indicating that they had a particularly sensitive sense of smell. One participant reported having a deviated septum that often interfered with her ability to smell. A single participant indicated that she had experienced two mild concussions in childhood, and a second indicated that she had had a broken nose. We did not screen for birth control use; 15 of our participants reported taking hormonal birth control at the time of the study.

2.2. Procedure. The study consisted of four parts: 1) a preparatory session, 2) an online snap judgment task, 3) diplomatic odor collection, and 4) a live speed friending session and diplomatic odor t-shirt ratings.

2.2.1. Preparatory session. Participants made preparatory appointments with a researcher approximately two weeks before the live speed friending session. During this appointment, participants signed a consent form and were given a clean cotton t-shirt in a ziplock bag for the odor collection portion of the study. Participants were also asked to pose for a photograph to be used in the snap judgment task. Photos were taken against a plain white wall with participants looking straight at the camera. Researchers took two to four photographs: one with participants making a neutral expression and one with participants smiling at the camera. If participants wore glasses, these same two photos were taken both with and without glasses. In post-production, photos were cropped so that the participant's face was centered in the photo, with minimal space at the top of the head. Bottom margins were aligned just below the collarbone and side margins were aligned approximately with the AC joint, where shoulders begin to slope downwards.

2.2.2. Online snap judgment task and additional measures. Following the preparatory session, participants were instructed to go online from any computer to complete a snap judgment task (described below) as well as a number of intake surveys. The intake surveys included a demographics questionnaire; questions about olfactory function and odor sensitivity; the Big Five Inventory (BFI-44), which assesses extraversion, openness, conscientiousness, neuroticism and agreeableness (Benet-Martínez & John, 1998); and an English translation of the Inventar Sozialer Kompetenzen (ISK), a German inventory of social skills (Scherp, 2010), as one study suggests that individuals high in one of the measured skills, social openness, might find body odor to be more significant and rewarding (Lübke et al., 2014). All participants completed the online portion at least two days before the live speed friending event.

During the snap judgment task, participants viewed between 36 and 40 faces presented for 50ms each. Participants answered a total of four questions about each face. Each face was presented four times, each followed by one of the four questions, with the entire set of faces and questions presented in a randomized order. All questions displayed the words "This seems like a person whom…" followed by one of four completing phrases: "I would like to get to know," "I would like to share a social activity with," "I would like to be friends with," or "I would prefer NOT to hang out with." Participants indicated their answers for each question on a 7-point Likert scale anchored on either end with "strongly disagree" and "strongly agree." For each question, participants saw one 50ms presentation of a face, then the face was replaced by the presented question, which remained on the screen until participants made their rating. At the end of the task, we asked participants if they had viewed photographs of anyone they knew. If the person was more than a passing acquaintance (e.g., "this person is in my history class but I don't know their name"), we ensured that both participants were placed in the same group or moved to separate days so they would not "meet" each other in the speed friending session.

2.2.3. Diplomatic odor collection. Between one and three days before the speed friending event, participants wore their t-shirt for approximately 12 hours, as they went about their daily activities. Most participants reported donning their shirts between 7 and 10 am and removing them between 7pm and 12am, though one person reported wearing their shirt overnight rather than during the day. Participants were asked to choose the least stressful of these three days to wear their shirt, as the study was conducted near the end of the semester and we knew students might be taking exams during this time. Because we were interested in capturing daily diplomatic odors, participants were asked not to make any modifications to their daily hygiene or habitual routines. They were asked, however, to avoid smoking or drinking alcohol, as well as strenuous exercise, being in particularly smelly locations such as smoky bars, and engaging in sexual activity. If participants wore perfume or other fragranced products during odor collection, they were asked to wear the same products to the speed friending session. At the end of the collection period, participants placed their shirt back into the provided ziplock bag and placed it in their freezer, then brought the shirt with them to the speed friending session. Participants were also asked to fill out an activity log for the day of odor collection regarding how long and at what times they wore the shirt, how it was stored, their stress level throughout the day, and whether or not they engaged in any of the prohibited activities.

2.2.4. Speed friending session and diplomatic odor judgments. On the day of the speed friending session, participants were asked to arrive in one of two locations, in order to avoid participants in opposite groups meeting one another before the study began. The stationary group (participants designated to remain seated in a specific location throughout the speed friending session) met in the lobby of the building where the speed friending session was to take place, while the traveling group (participants who traveled from one stationary participant to another) met in a nearby building. Both groups were first asked to fill out a brief "day of" questionnaire about their health, mental state, and menstrual cycle. While participants were filling out the questionnaire, experimenters labeled the bags containing their *t*-shirts with arbitrary numbers, and the *t*-shirts from each group were exchanged so that the stationary group smelled the shirts of the traveling group and vice versa.

2.2.4.1. Diplomatic t-shirt judgments. Prior to the speed friending event, participants in each group were provided with gloves, a packet of rating sheets, a pen, and a randomized list of *t*-shirt numbers to ensure that shirts were smelled in a random order for each individual. Shirts (in their bags) were placed individually on tables throughout the room, and participants circulated to each shirt. For each shirt, participants were instructed to open the bag, take a single deep sniff, and close the bag before answering all questions on the rating sheet (see section 2.2.4.2 for details). Following the speed-friending event, participants were led back to their original meeting location and directed to rate the same t-shirts, but in a new randomized order, again following the described methods above.

2.2.4.2. First impression rating sheets. Participants used identical rating sheets for judgments based on *t*-shirts as well as live speed friending interactions. Rating sheets asked participants to judge pleasantness and intensity of body odor, then to rate, based on the body odor or interaction, how attractive, likeable, competent, trustworthy, aggressive, and friendly the person was. Participants indicated answers on 7-point Likert scales anchored by "not at all" and "extremely." These ratings were followed by the same set of questions that participants answered in the snap judgment task ("this seems like the kind of person whom…I would like to get to know; share a social activity with; be friends with; prefer NOT to hang out with). Finally, participants were asked to make a series of personality judgments, rating the person in question on Likert scales anchored by the following 5 pairs of personality adjectives: reserved, quiet/extraverted, enthusiastic; critical, quarrelsome/sympathetic, warm; disorganized, careless/dependable, self-disciplined; anxious, easily upset/calm, emotionally stable; and conventional, uncreative/open to new experiences, complex. On the speed dating questionnaires, these questions were followed by the yes/no question, "would you like to exchange contact information with this participant?"

*2.2.4.3. Speed friending event***.** The speed friending event took place in the graduate student union on Cornell University's campus, a large, refurbished barn with a number of café tables spread throughout both a first floor and an open mezzanine level. Following the *t*-shirt ratings, stationary participants were led to chairs throughout the main speed friending room, where they would remain for the entirety of the speed friending session. Traveling participants were then brought to the speed friending location once all stationary participants were situated in their chairs. Each participant in the traveling group was randomly assigned to one of the tables around the room for their first meeting. Traveling participants proceeded from table to table in a clockwise rotation. Stationary participants were placed so that there was at least one empty table between each *meeting station* (table where a stationary participant was seated), distributed on both the first and second floor of the building. Because the second floor is open, all meeting stations were visible upon entering the room (see Figure 1).

Figure 1. View of the first floor with participants seated at meeting stations (A) and view of the open second floor (B).

In preparation for the speed friending session, all participants put on a name tag and received a packet of rating sheets identical to the ones used in the *t*-shirt ratings except for the additional question at the bottom, "would you like to exchange contact information with this person?" Both traveling and stationary participants were given the same information about meetings: each meeting would last four minutes, during which participants were to try to get to know the person seated opposite them. Following the meeting, traveling participants were to move to the next meeting station before both parties made their ratings, so that participants could not observe the ratings being made about their most recent meeting. Participants had two minutes between meetings to move to the next station (if traveling) and to make their ratings. At the end of the session, both groups returned to their original meeting places to complete the second round of *t*-shirt ratings.

2.2.4.4. Debriefing. At the end of the t-shirt rating session, participants were asked to fill out a brief survey asking them whether they thought they knew what the study was about, and, if so, to write down their guess as to the purpose of the study. Participants were then debriefed, allowed to ask any questions, and provided their compensation.

2.3. Data analytic strategy. All analyses performed using SPSS Version 20.

2.3.1. Creating aggregate scores. We created three aggregate scores to consolidate closely related variables in our data. The *liking* aggregate is composed of ratings for attractiveness, likeability, competency, trustworthiness, and friendliness. These items showed strong inter-item reliability; for round 1 olfactory ratings, inter-item correlations ranged from .454 to .773, and Cronbach's α=.873. For round 2 olfactory ratings, correlations ranged from .639 to .820, with α=.932. Finally, for multimodal ratings, all inter-item correlations ranged from .331 to .745, α=.829. The *wanting* aggregate, which addresses more actionable judgments, consists of ratings for "I would like to get to know [this person]," "I would like to share a social activity with [this person]," "I would like to be friends with [this person]," and the reverse-coded scores for "I would prefer NOT to hang out with [this person]." These were only 4 questions asked in the snap judgment paradigm. For snap judgments, inter-item correlations ranged from .564 to .674, with Cronbach's α=.867. For round 1 of olfactory ratings, inter-item correlations ranged from .728 to .924, with Cronbach's α=.945. For round 2, correlations ranged from .732 to .923, α=.946. For the multimodal ratings, correlations ranged from .679 to .878, α=.931. Finally, the *empathy* aggregate is composed of personality judgments where opposing ends of the scale were labeled "critical, quarrelsome/sympathetic, warm," "disorganized, careless/dependable, self-disciplined," and "anxious, easily upset/calm, emotionally stable." For the first round of olfactory ratings, α=.755. Inter-item correlations ranged from .440 to .556. For the second round of olfactory ratings, α=.796, with correlations ranging from .493 to .626. Finally, for the multimodal ratings, α=.707 and correlations ranged from .737 to .540.

2.3.2. Correcting for multiple comparisons. Participants made a total of 17 judgments in each round of rating. Our three aggregates cover a combined total of 12 of these ratings, giving us a total of 5 individual variables and 3 aggregates, or 8 distinct judgments. In order to ensure that our overall experiment-wise error rate remained at .05, we applied a Bonferroni correction. Our p value cutoff is .0063 (.05/8 tests) to reflect this correction.

2.3.3. Creating mean olfactory rating scores. Because judgments were highly consistent across the two olfactory rating rounds (see 3.1), we created mean scores for use in the rest of our analysis. For single variables (pleasant smell, intense smell, uncreative/open, quiet/extraverted, and aggressive), we averaged round 1 and round 2 ratings, then standardized the resulting mean. For our aggregates, we averaged the *mean* scores for each individual component (created as described above). We then standardized the resulting mean.

2.3.4. Perceiver, subject, and dyad effects. In previous work, we found that olfactory-based social judgments were largely determined by idiosyncratic preferences, or the specific combination of the person smelling with the person being smelled (Gaby & Zayas, in review). In the present study, we were interested in whether a similar phenomenon could be observed across multiple modalities. In order to investigate this, we examined the amount of variance in each judgment contributed by *perceivers,* the people making the judgments, *subjects,* the people who were the objects of the judgments, and *dyads,* the specific pairing of subject and perceiver. We assessed the amount of variance contributed by the dyad by creating a unique label for each pair of participants. Because each member of a given dyad acted as both perceiver and subject (participants made mutual ratings of each other), we assigned the same label to interactions where perceiver A judged subject B as interactions where perceiver B judged subject A. This allowed us to determine the extent to which *mutual agreement* contributed to a given judgment (A rates B 4/7 on friendliness; B rates A 4/7 on friendliness). We refer to this variance component as *dyad* in our results. To assess these various contributions, we used mixed models with each specific rating as the dependent variable and no fixed predictor. We included perceiver, subject, and synchrony as random effects. We then examined the estimates of variance for these covariates. We interpreted the estimation of the residual variance as being due to *individual* effects, or the idiosyncratic preferences of each individual rater, as it is the remaining variance in the model not due to perceiver, subject, or synchrony effects. According to our previous work, we expected individual effects to be the largest contributor to variance in judgments (Gaby & Zayas, in review). We discuss effects separately for each covariate below. See Table 2 for specific values for all covariates and modalities.

3. Results.

3.1. How consistent are participants' olfactory-based judgments? We used multilevel models (MLMs) with a restricted maximum likelihood estimation (Hayes, 2006) to ascertain whether olfactory-based judgments for each particular variable in round 1 predicted judgments for that variable in round 2. We used the round 2 ratings as the dependent variable and round 1 ratings as the fixed predictor, and included rater and donor as random effects. Ratings were standardized to facilitate interpretation of the slope coefficient. We found that for the all variables except quiet/extraverted, round 1 ratings significantly predicted round 2 ratings (see Table 1 for details).

Table 1. Do round 1 olfactory-based judgments predict round 2 olfactory-based judgments?

Question	β	SE	*df*	*p*	95% CI
Pleasant Smell	.435	.045	370.674	**.000**	[.348, .523]
Intense Smell	.312	.048	373.912	**.000**	[.217, .406]
Liking Aggregate	.462	.040	351.601	**.000**	[.382, .541]
Attractive	.455	.043	317.964	**.000**	[.370, .540]
Likeable	.380	.044	349.713	**.000**	[.294, .466]
Competent	.290	.045	370.875	**.000**	[.202, .379]
Trustworthy	.331	.044	386.357	**.000**	[.245, .416]
Friendly	.375	.041	380.573	**.000**	[.294, .455]
Wanting Aggregate	.445	.043	366.793	**.000**	[.359, .530]
Get to know	.431	.044	360.971	**.000**	[.344, .518]
Share an activity	.399	.045	382.965	**.000**	[.310, .487]
Be friends	.434	.043	381.265	**.000**	[.349, .519]
Not hang out (reverse coded)	.282	.046	377.769	**.000**	[.190, .373]
Empathy aggregate	.378	.046	387.011	**.000**	[.287, .468]
Critical/Sympathetic	.284	.049	371.069	**.000**	[.188, .379]
Disorganized/Dependable	.309	.047	389.804	**.000**	[.217, .402]
Anxious/Calm	.328	.047	384.165	**.000**	[.236, .420]
Uncreative/Open to experiences	.167	.049	385.336	**.001**	[.072, .262]
Quiet/Extraverted	.123	.049	385.102	.012	[.027, .219]
Aggressive	.155	.045	381.374	**.001**	[.066, .243]

Notes. Estimates based on standardized scores (z-scores). β represents the level 1 slope coefficient for round 1 olfactory-based judgments predicting round 2 olfactory-based judgments. Larger positive coefficients represent greater within-rater consistency across the two rating sessions. Because we performed 17 different analyses, with 12 of those included in our aggregates, we applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our *p* value cutoff is .0063 (.05/8) to reflect this correction. Values in bold indicate *p* values that remain significant once our correction is applied. Right-justified variables are those included in the aggregate variable above.

3.2. Interpersonal effects. As described in our data analytic strategy (2.3.4), we examined directionality, perceiver, subject and synchrony effects for each of our variables. See Table 2 for specific values.

3.2.1. Individual effects. We found that for the great majority of our variables in all three modalities, individual effects, or a particular perceiver's judgments about a specific subject, were the largest contributor to variance. This suggests that judgments are most strongly affected by an individual's idiosyncratic preferences for a particular subject. There were three variables for which this was not the case: multimodal ratings of both pleasantness and intensity of body odor, and multimodal ratings of quiet/extraverted. For multimodal ratings of body odor pleasantness, response variance was most heavily contributed by the perceiver (σ^2=.689, p<.001). This pattern was also observed in multimodal ratings of odor intensity (σ^2=1.530, p<.001). Taken together, these differences suggest that ratings of body odor were most strongly influences by a perceiver's olfactory sensitivity, rather than the particular subject they were judging. Finally, for multimodal ratings of quiet/extraversion, the largest amount of variability was contributed by the subject (σ^2=1.552, p<.001), suggesting that some subjects were judged by all perceivers to be more quiet or extraverted than others.

3.2.2. Perceiver effects. With the exception of multimodal judgments of quiet/extraverted (σ^2=.129, p=.054), perceiver effects contributed significantly to variance in all judgments. This suggests that, in addition to idiosyncratic preferences, judgments rely heavily on individual perceivers' global preferences. In other words, judgments were strongly affected by perceivers' tendency to rate *all* subjects either high or low on a given scale. In the next section, we attempt to ascertain whether these perceiver effects are moderated by personality variables.

3.2.3. Subject effects. Subject effects also influenced variability, though not for all judgments. We observed subject effects for our wanting aggregate in all three modalities (σ^2=.307, p<.001 for multimodal judgments; σ^2=.227, p<.001 for olfactory judgments, and σ^2=.300, p<.001 for visual judgments). We also observed subject effects for our liking aggregate in both multimodal and olfactory judgments (σ^2=.130,

$p<.001$ for multimodal judgments; $\sigma^2=.172$, $p<.001$ for olfactory judgments). We observed subject effects for olfactory judgments of empathy ($\sigma^2=.107$, $p<.05$), pleasant odor ($\sigma^2=.746$, $p<.01$), and intense odor ($\sigma^2=.502$, $p<.01$), and also for multimodal judgments of quiet/extraversion ($\sigma^2=1.552$, $p<.01$) and uncreative/open to experiences ($\sigma^2=.411$, $p<.01$). We did not observe any subject effects for judgments of aggression.

3.2.4. Dyad effects. Dyad effects contributed significantly to variance only for multimodal judgments of wanting ($\sigma^2=.226$, $p<.001$), suggesting that for the great majority of our variables, subjects and perceivers did not make similar judgments about each other. Importantly, the mutually agreed upon judgment of wanting is an aggregate encompassing actionable variables such as "I would like to hang out with this person," suggesting that participants did agree on whether or not they would be interested in pursuing a friendship with the other person. In fact, 64% of our dyads mutually agreed in the speed friending session about whether or not they would exchange contact information, significantly higher than chance ($\chi^2=15.68$, $p<0.001$).

Table 2. Variance in judgments contributed by individual, perceiver, subject and dyad effects.

Judgment	Individual	Perceiver	Subject	Dyad
Wanting Aggregate				
Multimodal Judgments	**.657****	**.194***	**.307****	**.226****
Olfactory Judgments	**.569****	**.435****	**.227****	.000
Visual Judgments	**.625****	**.417****	**.300****	.056
Liking Aggregate				
Multimodal Judgments	**.317****	**.218****	**.130****	.070
Olfactory Judgments	**.378****	**.252****	**.172****	.000
Empathy Aggregate				
Multimodal Judgments	**.557****	**.319****	.033	.000
Olfactory Judgments	**.477****	**.114***	**.107***	.035
Pleasant Smell				
Multimodal Judgments	**.545****	**.689****	.102	.000
Olfactory Judgments	**.933****	**.187***	**.746****	.000
Intense Smell				
Multimodal Judgments	**1.207****	**1.530****	.025	.000
Olfactory Judgments	**1.052****	**.577****	**.502****	.000
Aggressive				
Multimodal Judgments	**1.233****	**1.103****	.206	.000
Olfactory Judgments	**.634****	**.409****	.007	.065
Quiet/Extraverted				
Multimodal Judgments	**1.313****	.129	**1.552****	.202
Olfactory Judgments	**.671****	**.124***	.081	.036
Uncreative/Open to Experiences				
Multimodal Judgments	**1.318****	**.405****	**.411****	.000
Olfactory Judgments	**.474****	**.211****	.046	.093

Notes. Values are estimates of variance, based on raw scores (unstandardized). Because we performed 17 different analyses, with 12 of those included in our aggregates, we applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our *p* value cutoff is .0063 (.05/8) to reflect this correction. Values in bold indicate *p* values that remain significant once our correction is applied. ** denotes p<.01, * denotes p<.05.

3.3. Personality variables. We asked participants to fill out two different personality questionnaires, the BFI-44, which measures the Big 5 personality factors (extraversion, agreeableness, conscientiousness, neuroticism and openness), and the ISK, which is originally a German language personality questionnaire. In previous research, high scores in the ISK's measure of social openness correlated with perceivers finding body odor to be more significant and rewarding (Lübke et al., 2014). Though we asked participants all questions from the scale, which we translated into English, we only used the social openness measure for the purposes of this analysis. We used multilevel models with each judgment as the dependent variable and the five BFI44 measures as well as the ISK social openness measure as fixed predictors. We included perceiver, subject and dyad as random effects. We did not find any personality variables that moderated social judgments in any modality (all p's>.011; our p value cutoff is .0063 with our Bonferroni correction).

3.4. Do social judgments based on olfactory information predict social judgments in a multimodal speed friending paradigm? We used multilevel models (MLMs) with a restricted maximum likelihood estimation (Hayes, 2006) to assess whether olfactory judgments predicted multimodal judgments. We used the multimodal judgment as the dependent variable and the olfactory judgment of the same variable as the fixed predictor. We included perceiver, subject, and dyad as random effects. Olfactory judgments did not predict multimodal judgments for any of our variables. We found that individual effects contributed significantly to variance for all of our variables, and that for all variables except pleasantness and intensity of body odor and quiet/extraverted, individual effects contributed the greatest proportion of variance. Body odor ratings were again governed most strongly by perceiver effects, and quiet/extraverted again most strongly impacted by subject effects. Perceiver effects contributed significantly to variance for all variables except the wanting aggregate and quiet/extraverted. Subject effects contributed significantly to variance for wanting, liking, quiet/extraverted, and uncreative/open to experiences, and dyad effects contributed to variance only for the wanting aggregate (see Table 3 for detailed values).

Table 3. Do social judgments based on olfactory information collected on *t*-shirts predict social judgments in a multimodal speed friending paradigm?

Question	β	SE	*df*	*p*	95% CI	Individual	Perceiver	Subject	Dyad
Wanting Aggregate	0.065	0.052	297.350	.210	[-.037, .176]	**.483****	.122	**.213****	**.166***
Liking Aggregate	0.013	0.051	375.103	.800	[-.087, .113]	**.436****	**.292****	**.176****	.093
Empathy Aggregate	0.055	0.046	350.132	.232	[-.035, .145]	**.628****	**.340****	.029	.000
Pleasant Smell	0.057	0.043	268.101	.190	[-.028, .142]	**.414****	**.522****	.069	.000
Intense Smell	-0.009	0.043	208.277	.832	[-.093, .075]	**.440****	**.560****	.010	.000
Aggressive	-0.040	0.046	376.409	.387	[-.131, .051]	**.480****	**.456****	.083	.003
Quiet/Extraverted	-0.022	0.040	363.050	.589	[-.101, .057]	**.422****	.043	**.493****	.061
Uncreative/Open to Experiences	-0.017	0.049	385.260	.726	[-.113, .079]	**.626****	**.193****	**.195****	.000

Notes. Values based on standardized scores (z-scores). β represents the level 1 slope coefficient for olfactory-based judgments predicting multimodal judgments. Larger positive coefficients represent greater within-rater consistency across the two modalities. Because we performed 17 different analyses, with 12 of those included in our aggregates, we applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our *p* value cutoff is .0063 (.05/8) to reflect this correction. Shaded columns are estimates for variance contributed by each random effect. Values in bold indicate *p* values that remain significant once our correction is applied. ** denotes $p<.01$, * denotes $p<.05$.

3.5. Do snap judgments based on photographs predict social judgments in a multimodal speed friending paradigm? We used a similar model as described above to assess whether visual judgments predicted multimodal judgments. As we have only a single score from the snap judgments (the wanting aggregate), we used this as a predictor for each of the multimodal judgments. We used the multimodal judgment as the dependent variable and the visual score for our wanting aggregate as the fixed predictor, with perceiver, subject and dyad as random effects. We found that the visual wanting aggregate significantly predicted multimodal wanting (β=.211, p<.001), multimodal liking (β=.143, p=.006), and multimodal judgments of body odor pleasantness (β=.163, p=.001). We observed an identical pattern of variance components as we did for the relationship between olfactory and multimodal judgments (refer to Table 4 for detailed values).

3.6. Do snap judgments based on photos predict olfactory judgments based on body odor collected on *t*-shirts? We used a multilevel model with olfactory judgments as the dependent variable. As with our other models using snap judgments, we used the wanting aggregate as the fixed predictor for all variables and included perceiver, subject and dyad as random effects. We did not find any variables for which visual judgments predicted olfactory-based judgments, though we did find a different pattern of significant variance components. We again found that individual effects contributed strongly to all of our variables, but here we observed that individual effects were the largest contributors to variance for all of our variables. We found that perceiver effects contributed significantly to all variables except quiet/extraverted and, interestingly, pleasant smell. Subject effects contributed to variance for liking, wanting, empathy, and pleasant and intense smell, but dyad effects were not significant for any variable (see Table 5 for values).

Table 4. Do snap judgments based on photographs predict social judgments in a multimodal speed friending paradigm?

Question	β	SE	*df*	*p*	95% CI	Individual	Perceiver	Subject	Dyad
Wanting Aggregate	0.211	0.053	296.315	**.000**	[.107,.315]	**.457****	.098	**.222***	**.172***
Liking Aggregate	0.143	0.052	349.451	**.006**	[.040,.245]	**.414****	**.290***	**.161***	.105
Empathy Aggregate	0.091	0.053	256.311	.085	[-.013,.194]	**.620****	**.388****	.027	.000
Pleasant Smell	0.163	0.047	309.155	**.001**	[.070,.256]	**.368****	**.526****	.059	.026
Intense Smell	0.092	0.046	189.869	.045	[.002,.183]	**.437****	**.548****	.002	.026
Aggressive	0.045	0.052	329.524	.379	[-.056,.147]	**.513****	**.412****	.087	.000
Quiet/Extraverted	0.040	0.047	253.673	.390	[-.052,.133]	**.412****	.046	**.490****	.073
Uncreative/Open to Experiences	0.109	0.055	343.316	.046	[.002,.216]	**.599****	**.172***	**.181***	.000

Notes. Values based on standardized scores (z-scores). β represents the level 1 slope coefficient for snap judgments predicting multimodal judgments. Larger positive coefficients represent greater within-rater consistency across the two modalities. Because we performed 17 different analyses, with 12 of those included in our aggregates, we applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our *p* value cutoff is .0063 (.05/8) to reflect this correction. Shaded columns are estimates for variance contributed by each random effect. Values in bold indicate *p* values that remain significant once our correction is applied. ** denotes $p<.01$, * denotes $p<.05$.

Table 5. Do snap judgments based on photographs predict social judgments based on olfactory information collected on *t*-shirts?

Question	β	SE	*df*	*p*	95% CI	Individual	Perceiver	Subject	Dyad
Wanting Aggregate	0.078	0.052	356.644	.131	[-.023, .180]	**.479****	**.316****	**.192****	.000
Liking Aggregate	0.054	0.051	356.799	.289	[-.046, .155]	**.472****	**.270****	**.217****	.000
Empathy Aggregate	0.063	0.057	322.540	.273	[-.050, .175]	**.643****	**.156***	**.151***	.049
Pleasant Smell	-0.019	0.051	300.217	.713	[-.119, .082]	**.524****	.089	**.420****	.000
Intense Smell	0.042	0.054	355.318	.440	[-.064, .147]	**.528****	**.255****	**.262****	.000
Aggressive	-0.076	0.052	218.175	.142	[-.178, .026]	**.578****	**.372****	.008	.074
Quiet/Extraverted	-0.006	0.059	283.817	.916	[-.122, .110]	**.797****	.120	.095	.030
Uncreative/Open to Experiences	0.110	0.055	290.574	.045	[.002, .218]	**.532****	**.230****	.061	.152

Notes. Values based on standardized scores (z-scores). β represents the level 1 slope coefficient for snap judgments predicting olfactory-based judgments. Larger positive coefficients represent greater within-rater consistency across the two modalities. Because we performed 17 different analyses, with 12 of those included in our aggregates, we applied a Bonferroni correction to ensure that our overall experiment-wise alpha level remained at .05. Our *p* value cutoff is .0063 (.05/8) to reflect this correction. Shaded columns are estimates for variance contributed by each random effect. Values in bold indicate *p* values that remain significant once our correction is applied. ** denotes *p*<.01, * denotes *p*<.05.

3.7. What factors contribute to the decision to pursue contact with a partner beyond the speed friending event? For each person they met during the speed friending section of the study, participants had to indicate whether they would like to exchange contact information with that individual. We used multilevel models to determine if olfactory-based, visual-based, or multimodal measures of our aggregate variable for wanting predicted participants' decision to exchange contact information with an individual. We created a *contact* variable, where "yes, I'd like to exchange contact information with this person" was coded 1 and "no, I would not like to exchange contact information with this person" was coded 0. We then used this contact variable as the dependent variable in our mixed models, with the aggregate measure of wanting in each modality as the predictor in each model. As in previous models, we included perceiver, subject, and dyad as random effects. Multimodal measurements of wanting strongly predicted desire for contact (β=.309, p<.001). However, neither olfactory-based or visual-based measurements of wanting predicted our contact variable (β=.019, p=.446 for wanting based on olfactory information and β=.026, p=.332 for wanting based on visual information).

4. Discussion

We set out to answer three main questions: 1) do olfactory-based judgments predict multimodal judgments, 2) do photo-based snap judgments predict multimodal judgments, and 3) do olfactory-based judgments relate to visual judgments? We predicted that we would observe positive relationships between variables for each of these three cases. In contrast with our first hypothesis, we found no relationship between olfactory-based social judgments and those made in the speed friending session. We did, however, find support for our second hypothesis: first impressions based on visual assessment of facial photographs predicted first impressions in a multimodal speed friending paradigm. Finally, we found no relationship between first impressions based on olfactory information presented on *t*-shirts and first impressions based on photographs, contrary to our third hypothesis.

The strong relationship we observed between visual and multimodal first impressions is supported by previous research (Cooper et al., 2012; Gunaydin, Selcuk, & Zayas, 2016). Consistent with research by Cooper et al. (2012), in our study visual preferences were governed first and foremost by idiosyncratic preferences. Particularly for judgments of liking and wanting to pursue a friendship, the variance in the relationship between visual and multimodal judgments also depended on subject effects, suggesting that perceivers displayed universal agreement about subjects for these judgments in both modalities. Our results indicate that visual information strongly affects multimodal impressions, providing support for the notion that humans are highly reliant on visual input.

The lack of relationship we observed between visual and olfactory judgments, and between olfactory and multimodal judgments, is somewhat surprising given prior associations between olfactory and visual judgments of attractiveness (Rikowski & Grammer, 1999; Roberts et al., 2011; Thornhill et al., 2003). Despite this discrepancy, it is important to note that olfactory-based judgments were remarkably consistent across the two round of ratings. This indicates that perceivers do display reliable preferences based on olfactory information, even though these preferences may not influence multimodal judgments. In this study, we did our best to replicate the types of social interactions that exist in the real world – encounters with unknown others that take place at a social distance. It is possible that the distances used in our study, with participants seated across café tables from one another, were too great for the reliable exchange of olfactory information. Alternatively, it is possible that our participant numbers were too low for us to detect an effect.

Judgments of body odor pleasantness and intensity in multimodal interactions were governed most strongly by perceiver effects, suggesting that perceivers' judgments of body odor relied mostly on individuals' tendency to judge all body odors as pleasant or unpleasant, regardless of subject. Visual judgments of wanting also predicted multimodal judgments of body odor pleasantness, suggesting that multimodal body odor ratings may in fact be a reflection of the *halo effect*, or the tendency to judge a subject's individual attributes based on a global impression of that person rather than as independent measures (Nisbett & Wilson, 1977). It is possible that if our participants had shared a closer physical space, they would have had a better opportunity to assess olfactory information independently, and one might still expect to see a relationship between olfactory judgments and multimodal judgments in interactions where participants are physically closer together. In fact, it has been proposed that the handshake may be a means for exchanging olfactory information with an unknown other (Frumin et al., 2015), and it is possible that if we had included a handshake greeting in each of our meetings, we would have circumvented the problem of physical distance between participants.

Olfactory information is often processed below the level of conscious awareness (Lundström, Boyle, Zatorre, & Jones-Gotman, 2009), with conscious attention directed to an odor only if it indicates danger, food, or something emotionally salient. We might therefore expect that olfactory judgments would not readily accessible for self-report in a multimodal interaction unless an individual's body odor somehow violates one's expectations. Because our participants were taken from a fairly homogenous pool (female undergraduates at Cornell), it is likely that all of them adhered to generally accepted standards of diplomatic odor presentation, such as wearing deodorant and popular American perfumes at socially acceptable levels. If no individual's body odor was particularly noteworthy, it is possible that our metric was simply not able to capture the influence of body odor in multimodal interactions. There remains, of course, the possibility that in a first meeting, visual information simply supersedes olfactory information due to the necessity of making broad, general decisions about an individual in as short a time as possible.

4.1. Future directions. A motivation for this study was to investigate the influence of olfactory information in ecologically valid social interactions, rather than in the unrealistic context in which body odor is often encountered in the lab. Very few studies to date, if any, have explicitly attempted to replicate laboratory-based findings in real world settings, and it is difficult to conclude that the olfactory information available in a laboratory setting where axillary sweat free from exogenous fragrances is presented directly into the nostrils is also available in ecologically relevant situations where perceivers encounter others wearing fragrances and at a social distance. Future research should investigate whether olfactory information holds more influence when participants are physically closer together, or exchange olfactory information explicitly, as with a handshake. Given evidence that olfactory information becomes more informative with increasing familiarity (Zhou & Chen, 2011), it is also possible that olfactory-based effects could be observed if participants were allowed to engage in repeated meetings, another potential avenue for future research.

4.2. Conclusion. Our results provide evidence that visual information affects multimodal first impressions of others. Though participants displayed consistent olfactory preferences for unknown others based on their *t*-shirts, these judgments did not predict preferences in multimodal interactions. We suggest that future research examining the influence of olfactory information in realistic social interactions should either place participants in closer physical proximity to one another or incorporate multiple meetings in order to further investigate the longitudinal influence of body odor on social judgments.

References

Allen, C., Havlíček, J., & Roberts, S. C. (2015). Effect of fragrance use on discrimination of individual body odor. *Frontiers in Psychology*, *6*(August), 1–7. http://doi.org/10.3389/fpsyg.2015.01115

Baron, R. A. (1986). Self-Presentation in Job Interviews: When There Can Be "Too Much of a Good Thing." *Journal of Applied Social Psychology*, *16*(1), 16–28. http://doi.org/10.1111/j.1559-1816.1986.tb02275.x

Benet-Martínez, V., & John, O. P. (1998). Los Cinco Grandes across cultures and ethnic groups: multitrait multimethod analyses of the Big Five in Spanish and English. *Journal of Personality and Social Psychology*, *75*(3), 729–750. http://doi.org/10.1037/0022-3514.75.3.729

Cooper, J. C., Dunne, S., Furey, T., & O'Doherty, J. P. (2012). Dorsomedial Prefrontal Cortex Mediates Rapid Evaluations Predicting the Outcome of Romantic Interactions. *Journal of Neuroscience*, *32*(45), 15647–15656. http://doi.org/10.1523/JNEUROSCI.2558-12.2012

de Groot, J. H. B., Smeets, M. a. M., Rowson, M. J., Bulsing, P. J., Blonk, C. G., Wilkinson, J. E., & Semin, G. R. (2015). A Sniff of Happiness. *Psychological Science,* (April), 0956797614566318-. http://doi.org/10.1177/0956797614566318

Fialová, J., Roberts, S. C., & Havlíček, J. (2016). Consumption of garlic positively affects hedonic perception of axillary body odour. *Appetite*, *97*, 8–15. http://doi.org/10.1016/j.appet.2015.11.001

Frumin, I., Perl, O., Endevelt-Shapira, Y., Eisen, A., Eshel, N., Heller, I., … Sobel, N. (2015). A social chemosignaling function for human handshaking. *eLife*, *4*, e05154. http://doi.org/10.7554/eLife.05154

Gaby, J. M., & Zayas, V. (2016). Smelling is telling: Human olfactory cues influence social judgments. *In Review*.

Gangestad, S. W., & Thornhill, R. (1998). Menstrual cycle variation in women's preferences for the scent of symmetrical men. *Proceedings. Biological Sciences / The Royal Society*, *265*(1399), 927–933. http://doi.org/10.1098/rspb.1998.0380

Gunaydin, G., Selcuk, E., & Zayas, V. (2016). Impressions Based on a Portrait Predict, 1-Month Later, Impressions Following a Live Interaction. *Social Psychological and Personality Science*. http://doi.org/10.1177/1948550616662123

Gunaydin, G., Selcuk, E., & Zayas, V. (2016). Impressions based on a portrait predict, one-month later, impressions following a live interaction. *Social Psychological and Personality Science*. http://doi.org/10.1177/1948550616662123

Günaydin, G., Zayas, V., Selcuk, E., & Hazan, C. (2012). I like you but I don't know why: Objective facial resemblance to significant others influences snap judgments. *Journal of Experimental Social Psychology*, *48*(1), 350–353. http://doi.org/10.1016/j.jesp.2011.06.001

Haviland-Jones, J. M., McGuire, T. R., & Wilson, P. (2016). Testing for Individual Differences in the Identification of Chemosignals for Fear and Happy: Phenotypic Super-Detectors, Detectors and Non-Detectors. *Plos One*, *11*(5), e0154495. http://doi.org/10.1371/journal.pone.0154495

Havlicek, J., & Lenochova, P. (2006). The effect of meat consumption on body odor attractiveness. *Chemical Senses*, *31*, 747–752. http://doi.org/10.1093/chemse/bjl017

Hayes, A. F. (2006). A primer on multilevel modeling. *Human Communication Research*, *32*(4), 385–410. http://doi.org/10.1111/j.1468-2958.2006.00281.x

Jacob, S., & McClintock, M. K. (2000). Psychological state and mood effects of steroidal chemosignals in women and men. *Hormones and Behavior*, *37*(1), 57–78. http://doi.org/10.1006/hbeh.1999.1559

Kohoutová, D., Rubešová, A., & Havlíček, J. (2012). Shaving of axillary hair has only a transient effect on perceived body odor pleasantness. *Behavioral Ecology and Sociobiology*, *66*(4), 569–581. http://doi.org/10.1007/s00265-011-1305-0

Lenochová, P., & Havlicek, J. (2008). *Human body odor individuality*. (J. L. Hurst, R. J. Beynon, S. C. Roberts, & T. D. Wyatt, Eds.)*Chemical Signals in Vertebrates 11*. New York, NY: Springer Science+Business Media. http://doi.org/10.1007/978-0-387-73945-8

Lenochová, P., Vohnoutová, P., Roberts, S. C., Oberzaucher, E., Grammer, K., & Havlíček, J. (2012). Psychology of fragrance use: Perception of individual odor and perfume blends reveals a mechanism for idiosyncratic effects on fragrance choice. *PLoS ONE*, *7*(3), 1–10. http://doi.org/10.1371/journal.pone.0033810

Lübke, K. T., Croy, I., Hoenen, M., Gerber, J., Pause, B. M., & Hummel, T. (2014). Does human body odor represent a significant and rewarding social signal to individuals high in social openness? *PLoS ONE*, *9*(4), 1–7. http://doi.org/10.1371/journal.pone.0094314

Lundström, J. N., Boyle, J. A., Zatorre, R. J., & Jones-Gotman, M. (2009). The neuronal substrates of human olfactory based kin recognition. *Human Brain Mapping*, *30*(8), 2571–2580. http://doi.org/10.1002/hbm.20686

Nisbett, R. E., & Wilson, T. D. (1977). The Halo Effect: Evidence for Unconscious Alteration of Judgments. *Journal of Feisonality and Social Psychology*, *35*(4), 250–256. http://doi.org/http://dx.doi.org.ezproxy.snhu.edu/10.1037/0022-3514.35.4.250

Olsson, M. J., Lundström, J. N., Kimball, B. a, Gordon, A. R., Karshikoff, B., Hosseini, N., … Lekander, M. (2014). The scent of disease: human body odor contains an early chemosensory cue of sickness. *Psychological Science*, *25*(3), 817–23. http://doi.org/10.1177/0956797613515681

Prehn-Kristensen, A., Wiesner, C., Bergmann, T. O., Wolff, S., Jansen, O., Mehdorn, H. M., … Pause, B. M. (2009). Induction of empathy by the smell of anxiety. *PloS One*, *4*(6), e5987. http://doi.org/10.1371/journal.pone.0005987

Rikowski, A., & Grammer, K. (1999). Human body odour, symmetry and attractiveness. *Proceedings. Biological Sciences / The Royal Society*, *266*(1422), 869–874. http://doi.org/10.1098/rspb.1999.0717

Roberts, S. C., Kralevich, A., Ferdenzi, C., Saxton, T. K., Jones, B. C., Debruine, L. M., … Havlicek, J. (2011). Body odor quality predicts behavioral attractiveness in humans. *Archives of Sexual Behavior*, *40*(6), 1111–1117. http://doi.org/10.1007/s10508-011-9803-8

Scherp, E. (2010). ISK - Inventar Sozialer Kompetenzen von Kanning (2009). *Zeitschrift Fur Arbeits- Und Organisationspsychologie*, *54*(4), 193–200. http://doi.org/10.1026/0932-4089/a000030

Sorokowska, A., Sorokowski, P., & Havlíček, J. (2016). Body Odor Based Personality Judgments: The Effect of Fragranced Cosmetics. *Frontiers in Psychology*, *7*(April). http://doi.org/10.3389/fpsyg.2016.00530

Tabak, J. A., & Zayas, V. (2012). The roles of featural and configural face processing in snap judgments of sexual orientation. *PLoS ONE*, *7*(5). http://doi.org/10.1371/journal.pone.0036671

Thornhill, R. (1999). The Scent of Symmetry A Human Sex Pheromone that Signals Fitness? *Evolution and Human Behavior*, *20*(3), 175–201. http://doi.org/10.1016/S1090-5138(99)00005-7

Thornhill, R., Gangestad, S. W., Miller, R., Scheyd, G., McCollough, J. K., & Franklin, M. (2003). Major histocompatibility complex genes, symmetry, and body scent attractiveness in men and women. *Behavioral Ecology*, *14*(5), 668–678. http://doi.org/10.1093/beheco/arg043

Woodward, S. L., Thompson, M. E., & Gangestad, S. W. (2015). Women exposed to the scents of fertile-phase and luteal-phase women : Evaluative , competitive , and endocrine responses. *Adaptive Human Behavior and Physiology*, *1*(4), 434–448. http://doi.org/10.1007/s40750-014-0019-8

Zhou, W., & Chen, D. (2011). Entangled chemosensory emotion and identity: familiarity enhances detection of chemosensorily encoded emotion. *Social Neuroscience*, *6*(3), 270–276. http://doi.org/10.1080/17470919.2010.523537

CHAPTER 5

DISCUSSION

The studies presented in this dissertation provide insight into the functional role of body odor in real life social interactions. In the first paper, I provide evidence that olfactory information is perceptible in naturalistic interactions, that participants are capable of gleaning consistent social information from others' body odors, and that the social value of body odor is modified by the presence of exogenous fragrances. In the second, I show that, in spite of the social differences between fragranced and unfragranced body odor, perfume does not interfere with olfactory signals of individual identity. Importantly, I also show that olfactory information can have cross-modal effects, such that visual social signals are modified by the presence of an aversively conditioned body odor. In the final paper, I confirm that visual information plays an important role in multimodal first impressions of others, but suggest that olfactory information based on diplomatic body odor may do so only at a subliminal level.

In spite of participants' clear social preferences based on diplomatic body odor, displayed across multiple studies in this dissertation, this information does not seem to be readily accessible in the brief multimodal interactions we examined in our speed friending study, suggesting that perhaps normal social distances allow for limited odor exchange, that olfactory judgments are not consciously accessible unless a body odor violates expectations, or that body odor has a limited role in first impressions. Evidence supports the idea that we do in fact attend to body odors in real life: familiar body odors are comforting (McBurney, Shoup, & Streeter, 2006; Rattaz, Goubet, & Bullinger, 2005; Shoup, Streeter, & McBurney, 2008), and one study even suggests that mother's body odor may facilitate response to therapy in autistic children (Parma, Bulgheroni, Tirindelli, & Castiello, 2013). Previous research provides ample evidence that the body odors of familiar others are identifiable (Lundström & Jones-Gotman, 2009; Mallet & Schaal, 1998; Porter et al., 1985) and informative (Porter & Winberg, 1999; Zhou & Chen, 2011). Zhou and Chen (2011) showed that accuracy in identifying emotional sweat increased with increasing length of relationship. All of this evidence points to the fact that knowledge about familiar body odors accumulates over time and is accessible in lasting relationships, suggesting that body odor learning may be a longitudinal process. Though mothers display nearly instant recognition of their infants (Russell, Mendelson, & Peeke, 1983), it seems probable that, for two strangers, multiple exposures may be necessary for olfactory learning in real life contexts. As relationships deepen, those involved tend to share closer physical proximity and more exchanges of physical affection (Hays, 1985), which may serve as an opportunity for increased odor sampling and therefore increased familiarity and odor-related learning over time.

Further, methodological constraints may make the identification of these processes difficult when applying laboratory-based work to real interactions. HLA has been proposed to contribute to human mate selection via body odor (Wedekind et al., 1995), and there is a wealth of research showing that participants make predictable choices regarding HLA type of potential mates. In general, people seem to prefer dissimilar alleles to their own when asked to rate the body odors of potential mates in the lab (Jacob et al., 2002; Pause et al., 1999, 2006). However, there is conflicting evidence regarding assortative mating based on HLA allelotype in real couples (see Hedrick & Black, 1997; Ihara, Akoi, Tokunaga, Takahashi, & Juji, 2000 for evidence against; Ober et al., 1997 for evidence supporting). A recent study shows that, indeed, partners who are sexually and emotionally satisfied display dissimilar HLA class I alleles (Kromer et al., 2016), which suggests that some of the behaviors we observe in the lab may genuinely extend into real life. Importantly, Kromer et al. (2016) contend that the success of their study depends on more stringent methods of HLA genotyping than employed in previous research. It is likewise probable, given the lack of consistent methodology across human body odor studies (Havlíček, Lenochová, Oberzaucher, Grammer, & Roberts, 2011; Wyatt, 2015), that we have yet to determine the most effective methodology for observing effects both in the lab and in ecologically relevant situations.

So, where do we go from here? There are a number of directions for future research that could help to elucidate the functions of body odor in real life interactions. Given my previous assertion that body odor learning may require multiple exposures, projects examining the longitudinal perception of body odor seem a reasonable place to start. One possible approach includes a project where freshmen from a college dorm are asked to rate the body odors of other students residing in close proximity to them. These students would then participate in longitudinal data collection regarding the development of friendships over time, as well as changes in perception of body odors of those same students, taking into account relationship closeness. A study like this would certainly enlighten us on the development of olfactory associations over time, and would lend itself well to explorations including neural response to body odors and whether they change as a friendship evolves.

A second line of work might investigate the perception of emotional odors in realistic interactions. Research suggests that axillary odors collected from participants undergoing highly emotional events conveys identifiable and emotionally affective information (Cantafio, 2003; de Groot et al., 2015; Prehn, Ohrt, Sojka, Ferstl, & Pause, 2006; Wudarczyk et al., 2016). Emerging evidence suggests that some of this information may also be contained in breath (Williams et al., 2016; Williams & Pleil, 2016). It has been proposed, very reasonably, that the function of emotional body odors is to convey important information to conspecifics in the absence of movement or sound (Lübke & Pause, 2015). It is apparent that these emotional odors are perceptible in the lab, when participants are exposed to natural axillary odor samples collected on *t*-shirts or pads (e.g., de Groot et al., 2015; Haviland-Jones, McGuire, & Wilson, 2016; Mujica-Parodi et al., 2009). However, to the best of my knowledge, there are no studies to date examining whether people are capable of perceiving these odors in ecologically relevant situations, or if odor donors are wearing antiperspirants, which block the secretion of some body odor precursors (Draelos, 2001), deodorants, or perfumes.

It is important to establish that emotional odors are perceptible in real interactions, and also to look at whether the success of these odors in conveying emotional information is affected by exogenous odors. A first step could be accomplished by employing a method similar to that used in the first two studies contained in this dissertation, where perceivers and subjects are seated next to each other, with perceivers wearing blindfolds and earplugs. With the increased availability of virtual reality headgear, it should be possible to immerse one participant in a highly emotional situation while leaving the other participant unaware of the valence of the emotional stimuli. A combination of physiological and behavioral measures, as well as explicit self-report, would be ideal for measuring perceived emotion, and subjects could participate in both natural and diplomatic odor conditions. Recent work reports that communication of anxiety occurs very quickly after the onset of anxiety-inducing stimuli (de Groot, Smeets, & Semin, 2015), and the setup proposed here would also provide ample opportunity to examine the time course of emotions conveyed via body odor.

Overall, the work contained in this dissertation supports the growing notion that human olfaction plays a vital role in daily life, beyond simply serving as a warning system for dangers such as smoke or food rancidity. It is clear that people make definitive social judgments based on the body odor of others, and that these judgments are modified by the presence of perfume. Though olfactory information may not be clearly accessible in a brief meeting, we cannot rule out the possibility that body odors play a part in evaluation of others and in associative learning during the course of relationship development. Most importantly, the work contained herein exposes the breadth of knowledge still to be gained in the area of human social olfaction, and it is the pursuit of this insight that should engender future work in clarifying the role of diplomatic body odor in ecologically relevant interactions. In particular, this work suggests that future studies should incorporate more ecologically relevant methods, including allowing participants to present their body odor as they would on a daily basis. The studies presented here afford a glimpse at some of the functions of human body odor and fragrances in daily life. These advances, which suggest clear avenues for future research, highlight the fact that there is still a wealth of questions to be explored.

References

Aksenov, A. A., Gojova, A., Zhao, W., Morgan, J. T., Sankaran, S., Sandrock, C. E., & Davis, C. E. (2012). Characterization of Volatile Organic Compounds in Human Leukocyte Antigen Heterologous Expression Systems: A Cell's "Chemical Odor Fingerprint." *ChemBioChem*, *13*(7), 1053–1059. http://doi.org/10.1002/cbic.201200011

Allen, C., Havlíček, J., & Roberts, S. C. (2015). Effect of fragrance use on discrimination of individual body odor. *Frontiers in Psychology*, *6*(August), 1–7. http://doi.org/10.3389/fpsyg.2015.01115

Ayabe-Kanamura, S., Schicker, I., Laska, M., Hudson, R., Distel, H., Kobayakawa, T., & Saito, S. (1998). Differences in perception of everyday odors: a Japanese-German cross- cultural study. *Chem Senses*, *23*(1), 31–38. http://doi.org/10.1093/chemse/23.1.31

Baron, R. A. (1981). Olfaction and Human Social Behavior: Effects of a Pleasant Scent on Attraction and Social Perception. *Personality and Social Psychology Bulletin*, *7*(4), 611–616. http://doi.org/0803973233

Baron, R. A. (1986). Self-Presentation in Job Interviews: When There Can Be "Too Much of a Good Thing." *Journal of Applied Social Psychology*, *16*(1), 16–28. http://doi.org/10.1111/j.1559-1816.1986.tb02275.x

Beauchamp, G., & Mennella, J. A. (2009). Early flavor learning and its impact on later feeding behavior. *Journal of Pediatric Gastroenterology and Nutrition*, *48 Suppl 1*(10), S25-30. http://doi.org/10.1097/MPG.0b013e31819774a5

Cantafio, L. C. (2003). *Human Olfactory Communication of Alarm and Safety*. Rutgers University. Retrieved from UMI Number: 3077089

Chen, D., & Haviland-Jones, J. (2000). Human olfactory communication of emotion. *Perceptual and Motor Skills*, *91*(3 Pt 1), 771–81. http://doi.org/10.2466/pms.2000.91.3.771

Croy, I., Bojanowski, V., & Hummel, T. (2013). Men without a sense of smell exhibit a strongly reduced number of sexual relationships, women exhibit reduced partnership security - A reanalysis of previously published data. *Biological Psychology*, *92*(2), 292–294. http://doi.org/10.1016/j.biopsycho.2012.11.008

de Groot, J. H. B., Smeets, M. a. M., Rowson, M. J., Bulsing, P. J., Blonk, C. G., Wilkinson, J. E., & Semin, G. R. (2015). A Sniff of Happiness. *Psychological Science*, (April), 0956797614566318-. http://doi.org/10.1177/0956797614566318

de Groot, J. H. B., Smeets, M. A. M., & Semin, G. R. (2015). Rapid stress system drives chemical transfer of fear from sender to receiver. *PLoS ONE*, *10*(2), 1–22. http://doi.org/10.1371/journal.pone.0118211 de Groot, J. H. B., Smeets, M. a M., Kaldewaij, A., Duijndam, M. J. a, & Semin, G. R. (2012). Chemosignals communicate human emotions. *Psychological Science*, *23*(11), 1417–24. http://doi.org/10.1177/0956797612445317

Dixit, S. (2001). Fragrance Selection in Consumer Care Products. *Chemical Weekly*, 173–175.

Doty, R. L. (2010). *The Great Pheromone Myth*. JHU press.

Doucé, L., Poels, K., Janssens, W., & De Backer, C. (2013). Smelling the books: The effect of chocolate scent on purchase-related behavior in a bookstore. *Journal of Environmental Psychology*, *36*, 65–69. http://doi.org/10.1016/j.jenvp.2013.07.006

Draelos, Z. (2001). Antiperspirants and the hyperidrosis patient. *Dermatologic Therapy*, *14*, 220–224. Retrieved from papers2://publication/uuid/62C55F7F-A210-4407-A175-9DF52784B986

Ferdenzi, C., Roberts, S. C., Schirmer, A., Delplanque, S., Cekic, S., Porcherot, C., … Grandjean, D. (2013). Variability of affective responses to odors: Culture, gender, and olfactory knowledge. *Chemical Senses*, *38*(2), 175–186. http://doi.org/10.1093/chemse/bjs083

Freyberg, R., & Ahren, M.-P. (2011). A Preliminary Trial Exploring Perfume Preferences in Adolescent Girls. *Journal of Sensory Studies*, *26*(3), 237–243. http://doi.org/10.1111/j.1745-459X.2011.00339.x

Gaillet-Torrent, M., Sulmont-Rossé, C., Issanchou, S., Chabanet, C., & Chambaron, S. (2014). Impact of a non-attentively perceived odour on subsequent food choices. *Appetite*, *76*, 17–22. http://doi.org/10.1016/j.appet.2014.01.009

Gallagher, M., Wysocki, C. J., Leyden, J. J., Spielman, A. I., Sun, X., & Preti, G. (2008). Analyses of volatile organic compounds from human skin. *Br J Dermatol*, *159*(4), 780–791. http://doi.org/10.1111/j.1365-2133.2008.08748.x.Analyses

Gildersleeve, K. A., Haselton, M. G., Larson, C. M., & Pillsworth, E. G. (2012). Body odor attractiveness as a cue of impending ovulation in women: Evidence from a study using hormone-confirmed ovulation. *Hormones and Behavior*, *61*(2), 157–166. http://doi.org/10.1016/j.yhbeh.2011.11.005

Guéguen, N. (2001). Effect of a perfume on prosocial behavior of pedestrians. *Psychological Reports*, *88*(3 Pt 2), 1046–8. http://doi.org/10.2466/pr0.2001.88.3c.1046

Haegler, K., Zernecke, R., Kleemann, A. M., Albrecht, J., Pollatos, O., Br??ckmann, H., & Wiesmann, M. (2010). No fear no risk! Human risk behavior is affected by chemosensory anxiety signals. *Neuropsychologia*, *48*(13), 3901–3908. http://doi.org/10.1016/j.neuropsychologia.2010.09.019

Hämmerli, A., Schweisgut, C., & Kaegi, M. (2012). Population genetic segmentation of MHC-correlated perfume preferences. *International Journal of Cosmetic Science*, *34*(2), 161–168. http://doi.org/10.1111/j.1468-2494.2011.00696.x

Haviland-Jones, J. M., McGuire, T. R., & Wilson, P. (2016). Testing for Individual Differences in the Identification of Chemosignals for Fear and Happy: Phenotypic Super-Detectors, Detectors and Non-Detectors. *Plos One*, *11*(5), e0154495. http://doi.org/10.1371/journal.pone.0154495

Havlíček, J., Lenochová, P., Oberzaucher, E., Grammer, K., & Roberts, S. C. (2011). Does Length of Sampling Affect Quality of Body Odor Samples? *Chemosensory Perception*, *4*, 186–194. http://doi.org/10.1007/s12078-011-9104-6

Havlicek, J., Murray, A. K., Saxton, T. K., & Roberts, S. C. (2010). Current issues in the study of androstenes in human chemosignaling. *Vitamins and Hormones*, *83*(C), 47–81. http://doi.org/10.1016/S0083-6729(10)83003-1

Havlíček, J., & Roberts, S. C. (2013). The Perfume-Body Odour Complex : An Insightful Model for Culture – Gene Coevolution ? In *Chemical Signals in Vertebrates 12* (pp. 185–195). New York, NY: Springer. http://doi.org/10.1007/978-1-4614-5927-9

Hays, R. B. (1985). A longitudinal study of friendship development. *Journal of Personality and Social Psychology*, *48*(4), 909–924. http://doi.org/10.1037/0022-3514.48.4.909

Hedrick, P. W., & Black, F. L. (1997). HLA and Mate Selection: No Evidence in South Amerindians. *The American Journal of Human Genetics*, *61*(3), 505–511. http://doi.org/10.1086/515519

Herz, R. S., Eliassen, J., Beland, S., & Souza, T. (2004). Neuroimaging evidence for the emotional potency of odor-evoked memory. *Neuropsychologia*, *42*(3), 371–378. http://doi.org/10.1016/j.neuropsychologia.2003.08.009

Higuchi, T., Shoji, K., Taguchi, S., & Hatayama, T. (2005). Improvement of nonverbal behaviour in Japanese female perfume-wearers. *International Journal of Psychology*, *40*(February 2012), 90–99. http://doi.org/10.1080/00207590444000050

Ihara, Y., Akoi, K., Tokunaga, K., Takahashi, K., & Juji, T. (2000). HLA and human mate choice: Tests on Japanese couples. *Anthropological Science*, *108*(2), 199–214. http://doi.org/10.1007/s13398-014-0173-7.2

Jacob, S., McClintock, M. K., Zelano, B., & Ober, C. (2002). Paternally inherited HLA alleles are associated with women's choice of male odor. *Nature Genetics*, *30*(2), 175–179. http://doi.org/10.1038/ng830

Johnston, R. E., & Bullock, T. a. (2001). Individual recognition by use of odours in golden hamsters: the nature of individual representations. *Animal Behaviour*, *61*(3), 545–557. http://doi.org/10.1006/anbe.2000.1637

Kippenberger, S., Havlíček, J., Bernd, A., Thaçi, D., Kaufmann, R., & Meissner, M. (2012). "Nosing Around" the human skin: What information is concealed in skin odour? *Experimental Dermatology*, *21*(9), 655–659. http://doi.org/10.1111/j.1600-0625.2012.01545.x

Kromer, J., Hummel, T., Pietrowski, D., Giani, A. S., Sauter, J., Ehninger, G., … Croy, I. (2016). Influence of HLA on human partnership and sexual satisfaction. *Scientific Reports*, *6*(August), 32550. http://doi.org/10.1038/srep32550

Kuukasjarvi, S., Eriksson, C. J. P., Koskela, E., Mappes, T., Nissinen, K., & Rantala, M. J. (2004). Attractiveness of women's body odors over the menstrual cycle: The role of oral contraceptives and receiver sex. *Behavioral Ecology*, *15*(4), 579–584. http://doi.org/10.1093/beheco/arh050

Lenochová, P., & Havlicek, J. (2008). *Human body odor individuality*. (J. L. Hurst, R. J. Beynon, S. C. Roberts, & T. D. Wyatt, Eds.)*Chemical Signals in Vertebrates 11*. New York, NY: Springer Science+Business Media. http://doi.org/10.1007/978-0-387-73945-8

Lenochová, P., Vohnoutová, P., Roberts, S. C., Oberzaucher, E., Grammer, K., & Havlíček, J. (2012). Psychology of fragrance use: Perception of individual odor and perfume blends reveals a mechanism for idiosyncratic effects on fragrance choice. *PLoS ONE*, *7*(3), 1–10. http://doi.org/10.1371/journal.pone.0033810

Li, W., Moallem, I., Paller, K. A., & Gottfried, J. A. (2007). Subliminal smells can guide social preferences. *Psychological Science*, *18*(12), 1044–1049. http://doi.org/10.1111/j.1467-9280.2007.02023.x

Lindqvist, A. (2012). Preference and Gender Associations of Perfumes Applied on Human Skin. *Journal of Sensory Studies*, *27*(6), 490–497. http://doi.org/10.1111/joss.12014

Lübke, K. T., Hoenen, M., & Pause, B. M. (2012). Differential processing of social chemosignals obtained from potential partners in regards to gender and sexual orientation. *Behavioural Brain Research*, *228*(2), 375–387. http://doi.org/10.1016/j.bbr.2011.12.018

Lübke, K. T., & Pause, B. M. (2014). Sex-hormone dependent perception of androstenone suggests its involvement in communicating competition and aggression. *Physiology and Behavior*, *123*, 136–141. http://doi.org/10.1016/j.physbeh.2013.10.016

Lübke, K. T., & Pause, B. M. (2015). Always follow your nose: The functional significance of social chemosignals in human reproduction and survival. *Hormones and Behavior*, *68*, 134–144. http://doi.org/10.1016/j.yhbeh.2014.10.001

Lundström, J. N., Boyle, J. A., Zatorre, R. J., & Jones-Gotman, M. (2008). Functional neuronal processing of body odors differs from that of similar common odors. *Cerebral Cortex*, *18*(6), 1466–1474. http://doi.org/10.1093/cercor/bhm178

Lundström, J. N., Gonçalves, M., Esteves, F., & Olsson, M. J. (2003). Psychological effects of subthreshold exposure to the putative human pheromone 4,16-androstadien-3-one. *Hormones and Behavior*, *44*(5), 395–401. http://doi.org/10.1016/j.yhbeh.2003.06.004

Lundström, J. N., & Jones-Gotman, M. (2009). Romantic love modulates women's identification of men's body odors. *Hormones and Behavior*, *55*(2), 280–284. http://doi.org/10.1016/j.yhbeh.2008.11.009

Mallet, P., & Schaal, B. (1998). Rating and recognition of peers' personal odors by 9-year-old children: an exploratory study. *The Journal of General Psychology*, *125*(1), 47–64. http://doi.org/10.1080/00221309809595576

Martins, Y., Preti, G., Crabtree, C. R., Runyan, T., Vainius, A. A., & Wysocki, C. J. (2005). Preference for human body odors is influenced by gender and sexual orientation. *Psychological Science*, *16*(9), 694–701. http://doi.org/10.1111/j.1467-9280.2005.01598.x

McBurney, D. H., Shoup, M. L., & Streeter, S. A. (2006). Olfactory Comfort : Smelling a Partner ' s Clothing During. *Journal of Applied Psychology*, *36*(9), 2325–2335.

Mennella, J. A., Jagnow, C., & Beauchamp, G. K. (2001). Prenatal and postnatal flavor learning by human infants. *Pediatrics*, *107*(6), E88. http://doi.org/10.1016/j.pestbp.2011.02.012.Investigations

Milinski, M., Croy, I., Hummel, T., & Boehm, T. (2013). Major histocompatibility complex peptide ligands as olfactory cues in human body odour assessment. *Proceedings of the Royal Society B: Biological Sciences*, *280*(January), 20122889. http://doi.org/10.1098/rspb.2012.2889

Milinski, M., & Wedekind, C. (2001). Evidence for MHC-correlated perfume preferences in humans. *Behavioral Ecology*, *12*(2), 140–149. http://doi.org/10.1093/beheco/12.2.140

Mujica-Parodi, L. R., Strey, H. H., Frederick, B., Savoy, R., Cox, D., Botanov, Y., … Weber, J. (2009). Chemosensory cues to conspecific emotional stress activate amygdala in humans. *Plos One*, *4*(7), e6415. http://doi.org/10.1371/journal.pone.0006415

Mutic, S., Parma, V., Brünner, Y. F., & Freiherr, J. (2015). You Smell Dangerous: Communicating Fight Responses Through Human Chemosignals of Aggression. *Chemical Senses*, *41*, bjv058. http://doi.org/10.1093/chemse/bjv058

Ober, C., Weitkamp, L. R., Cox, N., Dytch, H., Kostyu, D., & Elias, S. (1997). HLA and mate choice in humans. *American Journal of Human Genetics*, *61*, 497–504. http://doi.org/10.1086/515511

Olsson, M. J., Lundström, J. N., Kimball, B. a, Gordon, A. R., Karshikoff, B., Hosseini, N., … Lekander, M. (2014). The scent of disease: human body odor contains an early chemosensory cue of sickness. *Psychological Science*, *25*(3), 817–23. http://doi.org/10.1177/0956797613515681

Olsson, S. B., Barnard, J., & Turri, L. (2006). Olfaction and identification of unrelated individuals: Examination of the mysteries of human odor recognition. *Journal of Chemical Ecology*, *32*(8), 1635–1645. http://doi.org/10.1007/s10886-006-9098-8

Parma, V., Bulgheroni, M., Tirindelli, R., & Castiello, U. (2013). Body odors promote automatic imitation in autism. *Biological Psychiatry*, *74*(3), 220–226. http://doi.org/10.1016/j.biopsych.2013.01.010

Pause, B. M., Krauel, K., Eggert, F., Müller, C., Sojka, B., Müller-ruchholtz, W., & Ferstl, R. (1999). Perception of HLA-related body odors during the course of the menstrual cycle. In *** (Ed.), *Advances in Chemical Signals in Vertebrates* (pp. 201–207). New York, NY: Kluwer Academic/Plenum Publishers.

Pause, B. M., Krauel, K., Schrader, C., Sojka, B., Westphal, E., Müller-Ruchholtz, W., & Ferstl, R. (2006). The human brain is a detector of chemosensorily transmitted HLA-class I-similarity in same- and opposite-sex relations. *Proceedings. Biological Sciences / The Royal Society*, *273*(1585), 471–478. http://doi.org/10.1098/rspb.2005.3342

Penn, D. J., Oberzaucher, E., Grammer, K., Fischer, G., Soini, H. A., Wiesler, D., … Brereton, R. G. (2007). Individual and gender fingerprints in human body odour. *Journal of the Royal Society, Interface*, *4*(13), 331–340. http://doi.org/10.1098/rsif.2006.0182

Penn, D., & Potts, W. (1998). MHC-disassortative mating preferences reversed by cross-fostering. *Proceedings of the Royal Society of London, Series B*, *265*(1403), 1299–1306. http://doi.org/10.1098/rspb.1998.0433

Porter, R. H., Cernoch, J. M., & Balogh, R. D. (1985). Odor signatures and kin recognition. *Physiology and Behavior*, *34*(3), 445–448. http://doi.org/10.1016/0031-9384(85)90210-0

Porter, R. H., Makin, J. W., Davis, L. B., & Christensen, K. M. (1992). Breast-fed infants respond to olfactory cues from their own mother and unfamiliar lactating females. *Infant Behavior and Development*, *15*(1), 85–93. http://doi.org/10.1016/0163-6383(92)90008-T

Porter, R. H., & Winberg, J. (1999). Unique salience of maternal breast odors for newborn infants. *Neuroscience and Biobehavioral Reviews*, *23*(3), 439–449. http://doi.org/10.1016/S0149-7634(98)00044-X

Prehn, A., Ohrt, A., Sojka, B., Ferstl, R., & Pause, B. M. (2006). Chemosensory anxiety signals augment the startle reflex in humans. *Neuroscience Letters*, *394*(2), 127–130. http://doi.org/10.1016/j.neulet.2005.10.012

Prokop-Prigge, K. A., Greene, K., Varallo, L., Wysocki, C. J., & Preti, G. (2016). The Effect of Ethnicity on Human Axillary Odorant Production. *Journal of Chemical Ecology*, *42*(1), 33–39. http://doi.org/10.1007/s10886-015-0657-8

Rattaz, C., Goubet, N., & Bullinger, A. (2005). The calming effect of a familiar odor on full-term newborns. *Journal of Developmental and Behavioral Pediatrics : JDBP*, *26*(2), 86–92. http://doi.org/10.1097/00004703-200504000-00003

Roberts, S. C., Gosling, L. M., Spector, T. D., Miller, P., Penn, D. J., & Petrie, M. (2005). Body odor similarity in noncohabiting twins. *Chemical Senses*, *30*(8), 651–656. http://doi.org/10.1093/chemse/bji058

Roberts, S. C., Havlíček, J., & Petrie, M. (2013). Repeatability of odour preferences across time. *Flavour and Fragrance Journal*, *28*(4), 245–250. http://doi.org/10.1002/ffj.3142

Roberts, S. C., Little, C., Lyndon, A., Roberts, J., Havlicek, J., & Wright, R. L. (2009). Manipulation of body odour alters men's self-confidence and judgements of their visual attractiveness by women. *International Journal of Cosmetic Science, 31*(1), 47–54. http://doi.org/10.1111/j.1468-2494.2008.00477.x

Russell, M. J., Mendelson, T., & Peeke, H. V. S. (1983). Mothers ' Identification of their Infant 's Odors. *Ethology and Sociobiology*, *4*, 29–31. http://doi.org/10.1016/0162-3095(83)90005-5

Schaal, B., Marlier, L., & Soussignan, R. (1998). Olfactory function in the human fetus: evidence from selective neonatal. *Behav Neurosci*, *112*(6), 1438–1449. http://doi.org/10.1037/0735-7044.112.6.1438

Schaal, B., Marlier, L., & Soussignan, R. (2000). Human foetuses learn odours from their pregnant mother's diet. *Chemical Senses*, *25*(6), 729–737. http://doi.org/10.1093/chemse/25.6.729

Schellinck, H. M., Slotnick, B. M., & Brown, R. E. (1997). Odors of individuality originating from the major histocompatibility complex are masked by diet cues in the urine of rats. *Animal Learning & Behavior*, *25*(2), 193–199. http://doi.org/10.3758/BF03199058

Shoup, M. L., Streeter, S. A., & McBurney, D. H. (2008). Olfactory comfort and attachment within relationships. *Journal of Applied Social Psychology*, *38*(12), 2954–2963. http://doi.org/10.1111/j.1559-1816.2008.00420.x

Sorokowska, A., Sorokowski, P., & Havlíček, J. (2016). Body Odor Based Personality Judgments: The Effect of Fragranced Cosmetics. *Frontiers in Psychology*, *7*(April). http://doi.org/10.3389/fpsyg.2016.00530

Troccaz, M., Gaïa, N., Beccucci, S., Schrenzel, J., Cayeux, I., Starkenmann, C., & Lazarevic, V. (2015). Mapping axillary microbiota responsible for body odours using a culture-independent approach. *Microbiome*, *3*, 3. http://doi.org/10.1186/s40168-014-0064-3

Ventura, A. K., & Worobey, J. (2013). Early influences on the development of food preferences. *Current Biology*, *23*(9), R401–R408. http://doi.org/10.1016/j.cub.2013.02.037

Wedekind, C., Seebeck, T., Bettens, F., Paepke, A. J., Wedekind1, C., Seebeck2, T., … Paepke1, A. J. (1995). MHC-Dependent Mate Preferences in Humans. *Source: Proceedings: Biological Sciences*, *260*(1359), 245–249. http://doi.org/10.1098/rspb.1995.0087

Willander, J., & Larsson, M. (2007). Olfaction and emotion: the case of autobiographical memory. *Memory & Cognition*, *35*(7), 1659–1663. http://doi.org/10.3758/BF03193499

Williams, J., & Pleil, J. (2016). Crowd-based breath analysis: assessing behavior, activity, exposures, and emotional response of people in groups. *Journal of Breath Research*, *10*(3), 32001. http://doi.org/10.1088/1752-7155/10/3/032001

Williams, J., Stönner, C., Wicker, J., Krauter, N., Derstroff, B., Bourtsoukidis, E., … Kramer, S. (2016). Cinema audiences reproducibly vary the chemical composition of air during films, by broadcasting scene specific emissions on breath. *Scientific Reports*, *6*(April), 25464. http://doi.org/10.1038/srep25464

Woodward, S. L., Thompson, M. E., & Gangestad, S. W. (2015). Women exposed to the scents of fertile-phase and luteal-phase women : Evaluative , competitive , and endocrine responses. *Adaptive Human Behavior and Physiology*, *1*(4), 434–448. http://doi.org/10.1007/s40750-014-0019-8

Wudarczyk, O. A., Kohn, N., Bergs, R., Goerlich, K. S., Gur, R. E., Turetsky, B., … Habel, U. (2016). Chemosensory anxiety cues enhance the perception of fearful faces - an fMRI study. *NeuroImage*. http://doi.org/10.1016/j.neuroimage.2016.09.002

Wyatt, T. D. (2015). The search for human pheromones: the lost decades and the necessity of returning to first principles. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1804), 20142994–20142994. http://doi.org/10.1098/rspb.2014.2994

Zhou, W., & Chen, D. (2011). Entangled chemosensory emotion and identity: familiarity enhances detection of chemosensorily encoded emotion. *Social Neuroscience*, *6*(3), 270–276. http://doi.org/10.1080/17470919.2010.523537